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(NASA-CR-160106) MODIFICATIONS TO GIVE HOPE/MDC 2.0 THE CAPABILITY TC SOLVE FOR OR CONSIDER VENT FORCES: MISSION PLANNING, MISSION ANALYSIS, AND SOFTWARE FORMULATION (McDonnell-Douglas Technical Services) 83 p [illegible]1

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MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-8-036

MODIFICATIONS TO GIVE HOPE/MDC 2.0 THE CAPABILITY TO SOLVE FOR OR CONSIDER VENT FORCES

MISSION PLANNING, MISSION ANALYSIS, AND SOFTWARE FORMULATION

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22 JANUARY 1979

This Design Note is Submitted to NASA Under Task Order No. D1032, Task Assignment N, Contract NAS 9-15550.

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1.0 SUMMARY

This design note contains a description of the modifications necessary to give the Houston Operations Predictor/Estimator (HOPE) program the capability to solve for or consider vent forces. The HOPE program, with the above modifications, will be referred to in this paper as HOPE/VENT. A new HOPE version which will include HOPE/VENT as well as other recent program modifications is currently being prepared and will be released as HOPE/MDC 3.0.

The formulation of HOPE/VENT relies heavily on the venting capability which already exists in version MDC 2.0 of HOPE. The user must input an attitude timeline as well as vent on-off times. The program will solve for or consider the components of a vent in body coordinates. This approach conforms to the current HOPE formulation as well as the approach taken in the Real Time Computer Complex (RTCC) logic.

The verification of HOPE/VENT was naturally divided into two phases: solve for and consider capability. The solve for capability was tested using the existing venting logic in the dummy data mode. The consider capability was verified by comparing results with the HOPE/B8.02 IGS Burn Model. In the process of verifying the consider capability, numerous difficulties were encountered with the HOPE trajectory integrator. For the proper functioning of the consider vent force model, the present study suggests a modification of the integrator to invoke a restart when encountering vent force discontinuities.

Section 3.0 describes in detail the model implemented in solving for vent forces, while Sections 3.1 and 4.2 detail the integrator problems encountered. Appendix A provides a summary derivation of the mathematical principles applicable to solve/consider methodology.

2.0 INTRODUCTION

One of the many unique problems encountered in performing orbit determination processing for the Shuttle is the existence of unknown perturbative forces on the vehicle caused by venting various gases during orbital flight. Complicating the relatively simple effect of venting is the phenomenon of plume impingement. As gases are released, they interact with the various body surfaces of the vehicle, causing unknown accelerations. While the primary venting effect may be known beforehand, the secondary interaction with tail, wing and door surfaces is unknown. An additional effect is the existence of RCS uncoupled thrusting which is triggered by vent forces.

The method described in this design note, called the method of correction vents, presumes the existence of a nominal vent timeline which must be corrected by solving for unknown vent perturbations. Thus, the nominal timeline may represent the primary effect of venting while the correction vents correspond to plume impingement effects.

An active vent timeline may have forty (40) distinct entries in the HOPE vent table. Computer time limitations and questionable mathematical validity, however, suggest that solving explicitly for such a large number of vents would be impractical. Using the method of correction vents, instead, enables one to solve for a long term average vent error which may, in a least square error sense, realistically account for the effect of many error vents.

In implementing the method of correction vents, an attempt has been made to keep program changes small. Rather than writing entirely new subroutines, use has been made of existing code whenever possible. Also, the unusual step has been taken to adapt little-used Lunar MASCON internal storage logic in the current HOPE for implementation of the new vent force capability.

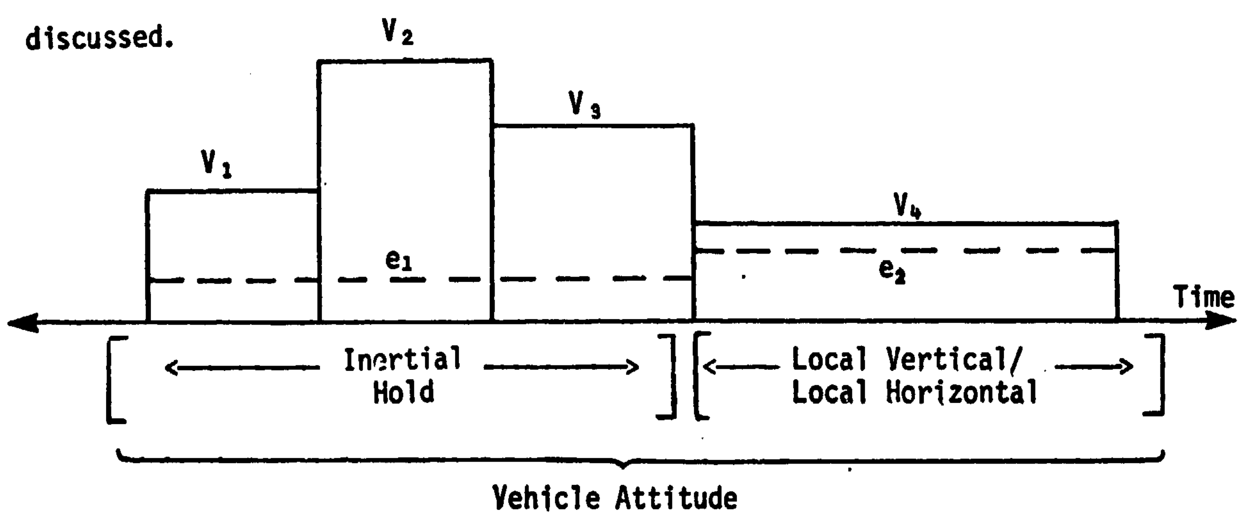
The resulting loss in MASCON computational capability was considered a justifiable tradeoff for having an up-to-date Shuttle era program developed per the established venting modifications schedule. Moreover, plans have been made for reincorporation of the MASCON capability (albeit without simultaneous execution of the venting calculations), pending completion of the present vent modification performance studies.

3.0 DISCUSSION

The approach being implemented can be best described as the method of correction or error vents. It is presumed that the user will input an attitude timeline and a table of nominal vents. The nominal vents are input in the body axis frame of the vehicle and should represent the user's best estimate of venting activity. The nominal vent timeline is input through the logic which already exists in HOPE version MDC 2.0 (References 1 and 2).

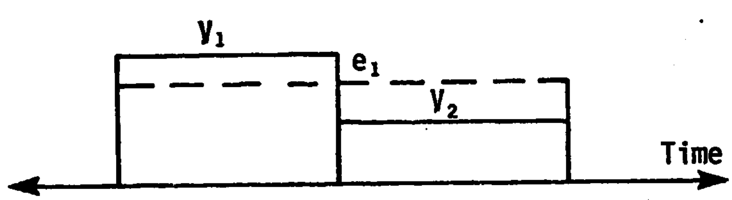
The vents to be solved for or considered, i.e., the correction vents, are viewed as updates or refinements to the nominal vent timeline. The correction vents are also input in the body axis frame and the steps necessary to do so are described in the user's section of this paper. Instead of solving for each nominal vent individually, the HOPE/VENT program solves for or considers an average vent error vector which can stretch over a fairly extended period of time. The number of such average error vents is limited; also, the user is required to input on-off times corresponding to each correction vent. The on-off times of the correction vents might represent special events in the vehicle attitude timeline, intervals of known extended vent activity, or other a priori vent information which the user might care to incorporate.

The following example illustrates the HOPE/VENT program nomenclature just discussed.



In the figure, the solid lines represent magnitudes of nominal vents, v_1, v_2, v_3, and v_4. The dashed lines represent correction vents, e_1, e_2. A point which should be stressed is that because of the computer implementation, start-stop times of correction vents must correspond to start and stop times of vents within the nominal table. This point is reiterated in the user's section. In this example, the correction vents are put at the boundaries of vehicle attitude changes, but this procedure is strictly up to the discretion of the user.

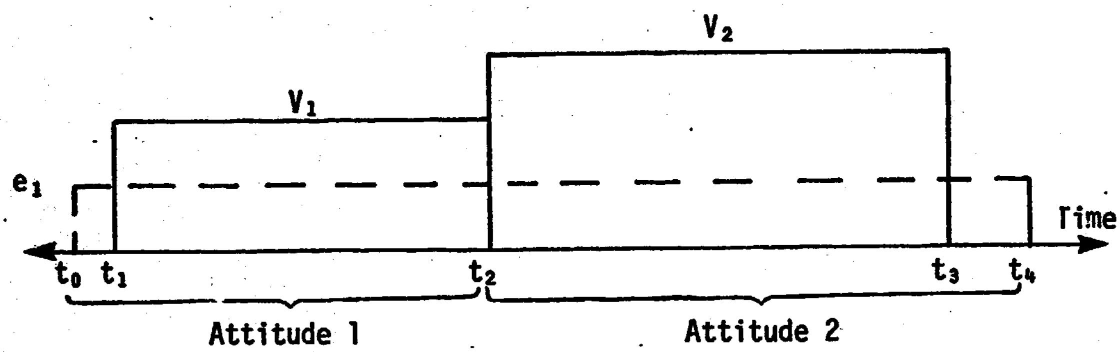
A note of mathematical caution about the use of correction vents: no single vent can account for the effect of two distinct vents on a vehicle trajectory. For example, consider the following simplified timeline.



Suppose the vehicle experiences two distinct vents, v_1 and v_2, indicated above by the solid lines. Mathematically, there is no single average vent, i.e., dotted line, which will produce the same vehicle trajectory after time, T, as two distinct vents, v_1 and v_2. See Reference 3 for a further discussion of this idea. The attempt to attribute many unknown error vent sources to one correction vent is, at best, an approximation.

3.1 THE VARIATIONAL EQUATIONS - INTEGRATION AND BOUNDS

Consider the following simplified vent timeline with one correction vent.



Note that the above timeline contains a vent straddling an attitude change. This is done for illustrative purposes only and is not the form one would implement on the computer.

The equations of motion can be written as follows:

$$\ddot{\vec{x}} = \vec{f}\,(\vec{x}, \dot{\vec{x}}, t) + \frac{k}{M} A_0 s_0(t)\,\vec{e}_1 + \frac{k}{M} A_0 s_1(t)\,(\vec{v}_1 + \vec{e}_1)$$

$$+ \frac{k}{M} A_1(t)\, s_2(t)\,(\vec{e}_1 + \vec{v}_2) + \frac{k}{M} A_1(t)\, s_3(t)\,\vec{e}_1. \qquad (1)$$

The function, $\vec{f}\,(\vec{x}, \dot{\vec{x}}, t)$, represents the accelerations due to all sources other than venting. The matrices, A_0 and $A_1(t)$, are transformation matrices from the body axis frame to the Mean of 1950 Coordinate System (MOF50). The step functions $\{s_i(t),\ i = 0,\ldots,3\}$ are defined by

$$s_i(t) = 1 \qquad t \in (t_i, t_{i+1})$$

$$s_i(t) = 0 \qquad \text{elsewhere.}$$

M is the vehicle mass (slugs) and k is a scale factor which converts ft/sec^2

to Erad/min^2 (earth radii per minute squared). Equation (1) is in a Cartesian Mean of 1950 coordinate system with vents appearing in the body axis frame in units of pounds force (lb_f).

Let the components of $\vec{e}_1 = \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix}$, and take the partial of Equation (1) with respect to parameter, z_1. Then

$$\frac{\partial \ddot{\vec{x}}}{\partial z_1} = \frac{\partial \vec{f}}{\partial \vec{x}} \frac{\partial \vec{x}}{\partial z_1} + \frac{\partial \vec{f}}{\partial \dot{\vec{x}}} \frac{\partial \dot{\vec{x}}}{\partial z_1} + \frac{k}{M} A_0 s_0(t) \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} + \frac{k}{M} A_0 s_1(t) \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

$$+ \frac{k}{M} A_1(t)\ s_2(t) \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} + \frac{k}{M} A_1(t)\ s_3(t) \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}. \tag{2}$$

Note the presence of step discontinuities in Equation (2), the variational equation. Care must be taken to integrate the variational equations accurately. The integration of the state equations also involves integrating through vent force discontinuities, but the vents are a small contribution to the total acceleration experienced by the vehicle. In Equation (2), however, the discontinuities are the sole driving functions. Section 4.0 contains a discussion of the effect of integration accuracy on the propagation of covariance matrices. A smoothing scheme, similar to the one used for the vent model in HOPE, is required to properly integrate the variational equations.

Figure 3-1 contains a flowchart and variable description of the smoothing logic implemented in integrating the variational equations.

An additional comment concerning the figure on page 6 is that the correction

FIGURE 3-1

SMOOTHING LOGIC VARIATIONAL EQUATIONS

FLOWCHART

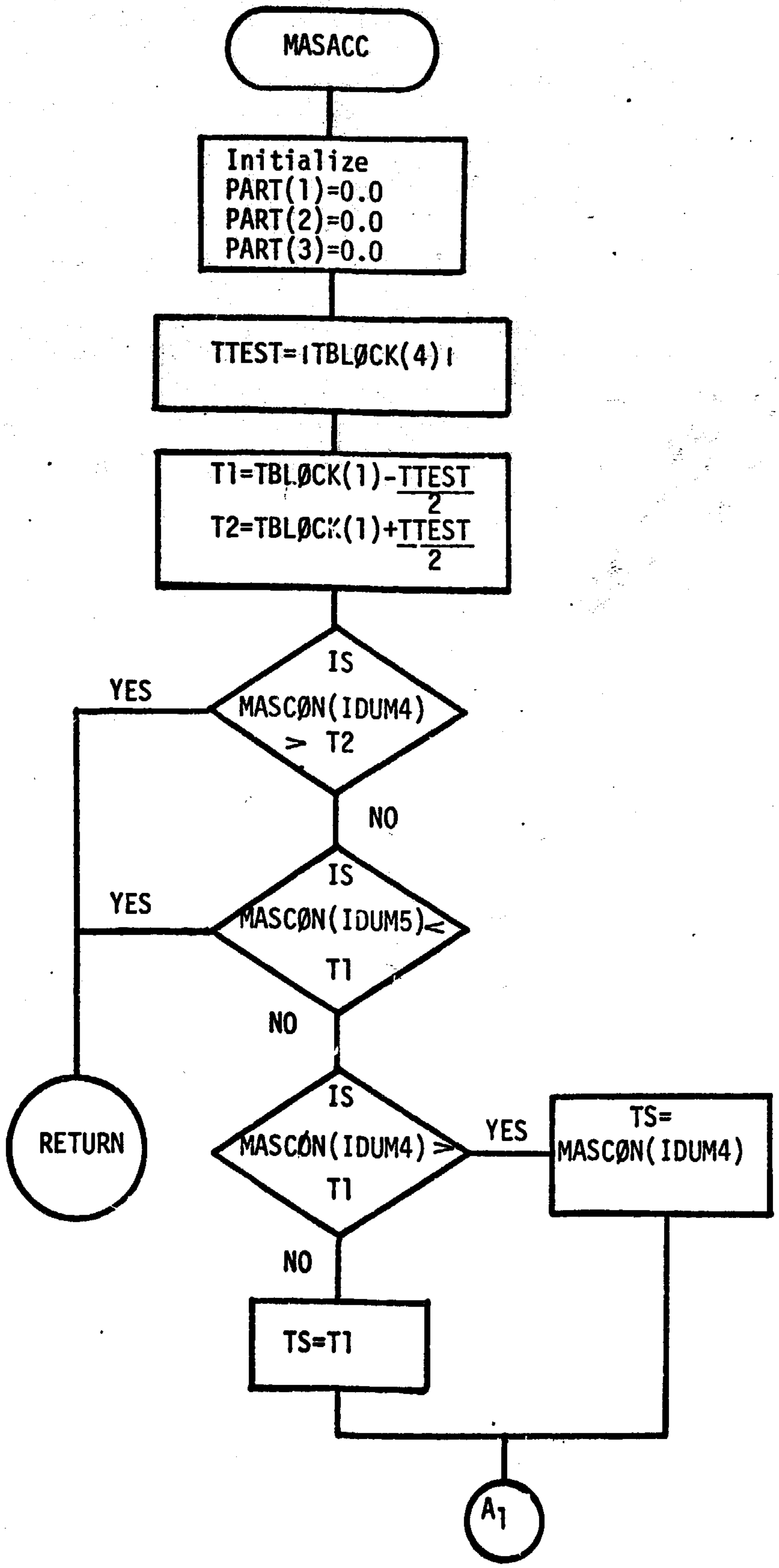


FIGURE 3-1 (Cont.)

SMOOTHING LOGIC VARIATIONAL EQUATIONS

FLOWCHART

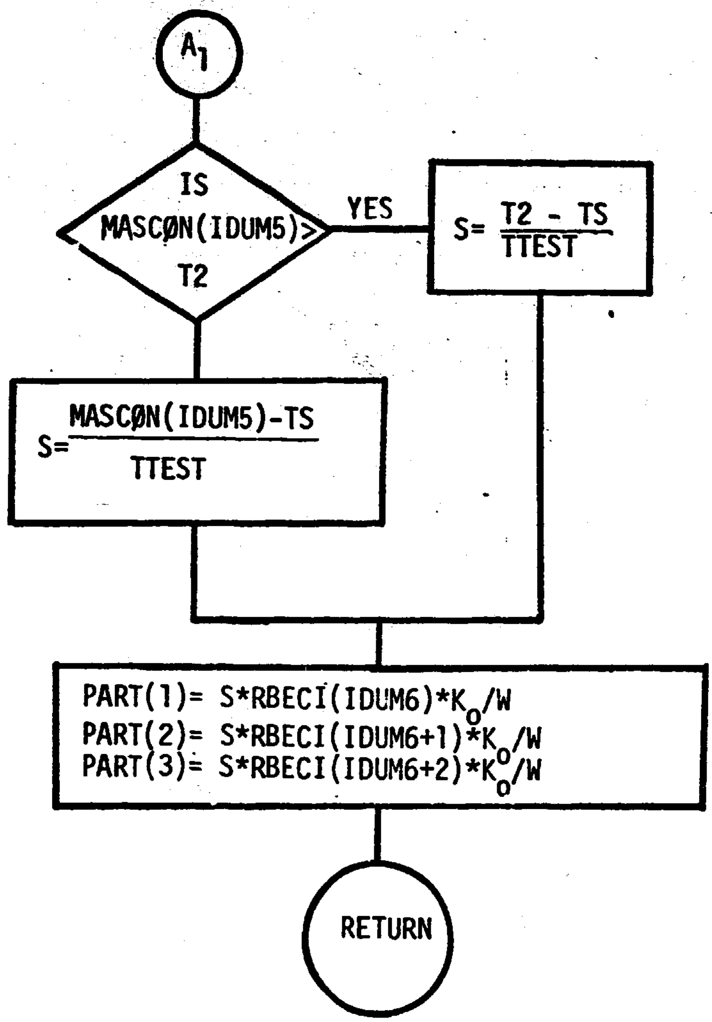


FIGURE 3-1 (Concluded)

SMOOTHING LOGIC VARIATIONAL EQUATIONS

FLOWCHART VARIABLES

PART(1)-PART(3) - forcing function in the right hand side of the variational equations.

TBLØCK(1) - current integration time points

TBLØCK(4) - integration step size

TTEST - integration averaging interval

MASCON(IDUM4) - start time of correction vent

MASCON(IDUM5) - stop time of correction vent

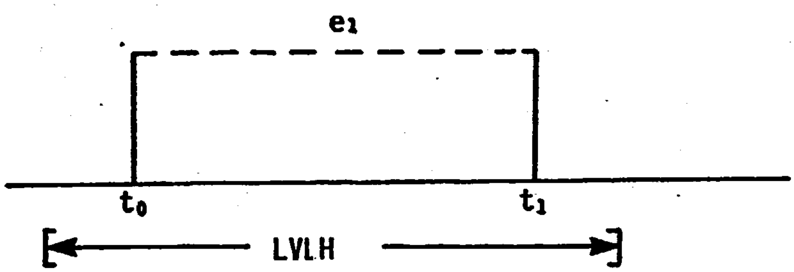
RBECI - transformation matrix from body to MØF50

K_0 - scaling constant which takes lb force to Erad/min^2

W - vehicle weight

vent, $\vec{e}_1$, is shown straddling an attitude change. Because of the implementation of the attitude routine, BODATT, in HOPE, attitude maneuvers are assumed to be instantaneous. This introduces additional discontinuities at points of attitude transition. The user would be advised to create two distinct correction vents out of the single vent, $\vec{e}_1$.

Now consider the following simplified vent timeline:



The equations of motion are:

$$\ddot{\vec{x}} = \vec{f}\,(\vec{x},\ v,\ t) + \frac{k}{M}\,A\,(\vec{x},\ \vec{v})\ s_0(t)\ R_0\ \vec{e}_1 \tag{3}$$

where $\vec{v} = \dot{\vec{x}}$, $A\,(\vec{x},\ \vec{v})$ is the transformation matrix which goes from the Local Vertical/Local Horizontal (LVLH) attitude to the Mean of 1950 system, and R_0 is the constant transformation matrix which goes from the body axis frame to LVLH. The matrix, $A\,(\vec{x},\ \vec{v})$, can be written as:

$$A\,(\vec{x},\ \vec{v}) = \left(\frac{(\vec{x} \times \vec{v}) \times \vec{x}}{|\vec{x} \times \vec{v}|\ |\vec{x}|} \ \vdots\ \frac{-\vec{x} \times \vec{v}}{|\vec{x} \times \vec{v}|} \ \vdots\ \frac{-\vec{x}}{|\vec{x}|} \right) . \tag{4}$$

Define the vectors:

$$\begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix} = R_0\ \vec{e}_1 \quad ,$$

$$\vec{a}_1 = \frac{(\vec{x} \times \vec{v}) \times \vec{x}}{|\vec{x} \times \vec{v}|\ |\vec{x}|} \quad ,$$

$$\vec{a}_2 = \frac{-\vec{x} \times \vec{v}}{|\vec{x} \times \vec{v}|} \quad ,$$

and

$$\vec{a}_3 = \frac{-\vec{x}}{|\vec{x}|} \quad .$$

Rewrite Equation (3) as:

$$\ddot{\vec{x}} = \vec{f}\,(\vec{x}, \vec{v}, t) + \frac{k}{M}\,(c_1\, \vec{a}_1\, (\vec{x}, \vec{v}) + c_2\, \vec{a}_2\, (\vec{x}, v) + c_3\, \vec{a}_3\, (\vec{x}, \vec{v})).$$

If $\vec{e}_1 = \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix}$, then

$$\frac{\partial \ddot{\vec{x}}}{\partial z_1} = \frac{\partial \vec{f}}{\partial x}\, \frac{\partial \vec{x}}{\partial z_1} + \frac{\partial \vec{f}}{\partial v}\, \frac{\partial \vec{v}}{\partial z_1} + \frac{k}{M}\, (\frac{\partial c_1}{\partial z_1}\, \vec{a}_1 + \frac{\partial c_2}{\partial z_1}\, \vec{a}_2 + \frac{\partial c_3}{\partial z_1}\, \vec{a}_3)$$

$$+ \frac{k}{M}\, (c_1\, (\frac{\partial \vec{a}_1}{\partial \vec{x}}\, \frac{\partial \vec{x}}{\partial z_1} + \frac{\partial \vec{a}_1}{\partial \vec{v}}\, \frac{\partial \vec{v}}{\partial z_1}) + c_2\, (\frac{\partial \vec{a}_2}{\partial \vec{x}}\, \frac{\partial \vec{x}}{\partial z_1} + \frac{\partial \vec{a}_2}{\partial \vec{v}}\, \frac{\partial \vec{v}}{\partial z_1})$$

$$+ c_3\, (\frac{\partial \vec{a}_3}{\partial \vec{x}}\, \frac{\partial \vec{x}}{\partial z_1} + \frac{\partial \vec{a}_3}{\partial \vec{v}}\, \frac{\partial \vec{v}}{\partial z_1}))\ . \qquad (5)$$

The terms, $\frac{k}{M}\, (c_1 \frac{\partial \vec{a}_1}{\partial \vec{x}} + c_2 \frac{\partial \vec{a}_2}{\partial \vec{x}} + c_3 \frac{\partial \vec{a}_3}{\partial \vec{x}})\, \frac{\partial \vec{x}}{\partial z_1}$, (6)

and

$$\frac{k}{M}\, (c_1 \frac{\partial \vec{a}_1}{\partial \vec{v}} + c_2 \frac{\partial \vec{a}_2}{\partial \vec{v}} + c_3 \frac{\partial \vec{a}_3}{\partial \vec{v}})\, \frac{\partial \vec{v}}{\partial z_1} \quad , \qquad (7)$$

can be grouped, respectively, with $\frac{\partial \vec{f}}{\partial \vec{x}} \frac{\partial \vec{x}}{\partial z_1}$ and $\frac{\partial \vec{f}}{\partial \vec{v}} \frac{\partial \vec{v}}{\partial z_1}$.

We shall now show that Terms (6) and (7) can be neglected in the variational equations. It can be seen by examining the partials of A $(\vec{x}, \vec{v})$ (Reference 4) that the following bounds exist:

$$\left\|\frac{\partial \vec{a}_1}{\partial \vec{x}}\right\| = \frac{1}{|\vec{x}|} \qquad \left\|\frac{\partial \vec{a}_1}{\partial \vec{v}}\right\| \leq k_3 \frac{1}{|\vec{v}|}$$

$$\left\|\frac{\partial \vec{a}_2}{\partial \vec{x}}\right\| \leq k_1 \frac{1}{|\vec{x}|} \qquad \left\|\frac{\partial \vec{a}_2}{\partial \vec{v}}\right\| \leq k_4 \frac{1}{|\vec{v}|} \tag{8}$$

$$\left\|\frac{\partial \vec{a}_3}{\partial \vec{x}}\right\| \leq k_2 \frac{1}{|\vec{x}|} \qquad \left\|\frac{\partial \vec{a}_3}{\partial \vec{v}}\right\| = 0$$

NOTE: $\|\cdot\|$ indicates matrix norm.

The constants, k_1, k_2, k_3, k_4, depend on the eccentricity of the orbit. For small eccentricities the constants are very close to unity.

Consider the following table which compares the relative magnitude of accelerations affecting the Shuttle with a weight of 200,000 lbs.

120 NM Circular Orbit

Acceleration Source		Acceleration
Earth central body	-	18 Erad/hr^2
Earth perturbations (J_2)	-	.02 Erad/hr^2
Venting (40 lb_f)	-	4.0×10^{-3} Erad/hr^2
Drag	-	3.0×10^{-4} Erad/hr^2
Sun-Moon perturbations	-	1.0×10^{-6} Erad/hr^2

Erad = Earth radii

Let us now examine the term, $\frac{\partial \vec{f}}{\partial \vec{x}} \frac{\partial \vec{x}}{\partial z_1} + \frac{\partial \vec{f}}{\partial \vec{v}} \frac{\partial \vec{v}}{\partial z_1}$, which appears in the right hand side of Equation (5). We shall only consider the contribution of the central force term to the total acceleration, $\vec{f}$.

The partial of the central gravity term is as follows:

$$\frac{\partial}{\partial \vec{x}} \left(\frac{\mu \vec{x}}{|\vec{x}|^3}\right) = \frac{\mu}{|\vec{x}|^3} I - 3\mu \frac{\vec{x}\vec{x}^T}{|\vec{x}|^5} , \tag{9}$$

where $\mu = 19.909$ Erad^3/hr^2. If $|\vec{x}| \approx 1.03$ Erad, then the partial of the central gravity term $\approx 36.4/\text{hr}^2$.

Expression (6) can be bounded by

$$c_1 \frac{\partial \vec{a}_1}{\partial \vec{x}} + c_2 \frac{\partial \vec{a}_2}{\partial \vec{x}} + c_3 \frac{\partial \vec{a}_3}{\partial \vec{x}} \leq || c || \max (1, k_1, k_2) \frac{1}{|\vec{x}|} , \tag{10}$$

where use has been made of bounds in Equation (8). Expression (7) can be bounded by

$$c_1 \frac{\partial \vec{a}_1}{\partial \vec{v}} + c_2 \frac{\partial \vec{a}_2}{\partial \vec{v}} + c_3 \frac{\partial \vec{a}_3}{\partial \vec{v}} \leq \| c \| \max (k_3, k_4) \frac{1}{|\vec{v}|} , \tag{11}$$

using the bounds in Equation (8).

For a 40 lb_f vent and a 120 nm orbit, Equation (10) can be further bounded by $3.8 \times 10^{-3}/hr^2$. Thus, the gravity term (Expression (9)) is roughly 10^4 times more significant than Term (6) in the variational equations. To further bound Expression (11), we must make use of Kepler's Third Law for the period of a circular orbit. For a circular orbit,

$$\frac{T^2}{|\vec{x}|^3} = \frac{4\pi^2}{\mu} \tag{12}$$

But we also know that $T = \dfrac{2\pi \, |\vec{x}|}{|\vec{v}|}$

so that $\dfrac{1}{|\vec{v}|} = \left(\dfrac{|\vec{x}|}{\mu}\right)^{1/2}$

Hence, Expression (7) can be bounded by

$$c_1 \frac{\partial \vec{a}_1}{\partial \vec{v}} + c_2 \frac{\partial \vec{a}_2}{\partial \vec{v}} + c_3 \frac{\partial \vec{a}_3}{\partial \vec{v}} \leq \| c \| \max (k_3, k_4) \frac{1}{|\vec{v}|} \leq \frac{\| c \| \, |\vec{x}|^{1/2}}{\mu^{1/2}}$$

or

$$\leq 1.4 \times 10^{-2}/hr^3 \tag{13}$$

Gravity (Expression (9)) is roughly 10^3 times more significant than this term.

Thus it appears that for orbits of small ellipticity, terms of the form

$\frac{\partial A}{\partial \vec{x}} (\vec{x}, \vec{v})$ and $\frac{\partial A (\vec{x}, \vec{v})}{\partial \vec{v}}$, represent a relatively insignificant contribution to the variational equations. These terms have not been included in the HOPE/VENT program, either in solving for venting parameters or solving for any other dynamic parameter.

3.2 PROGRAM MODIFICATION GUIDELINES

The guiding philosophy in implementing solve/consider venting forces in the HOPE/VENT program has been to use as much of the original code as possible. A little used capability to solve or consider Lunar MASCON parameters has been modified to accept venting parameters. Thus, instead of creating separate routines in the input processor, trajectory, and DC links of the program, the MASCON capability was used to set appropriate flags, dimension variables, and create the necessary memory locations. At the appropriate stage, however, MASCON variational equations were replaced with venting parameter variational equations.

The reasons for selecting MASCON parameters are threefold. First, the venting parameters are dynamic variables which must be integrated along a trajectory. The MASCON parameters are dynamic and thus no changes in the trajectory link would have to be made to accommodate new dynamic solve for or consider variables. Second, the venting parameters are an expandable set of variables depending, in number, on the program user. The MASCONs are also an expandable set of solve for or consider variables with a maximum of 100 MASCONS available to be solved for or considered. Thus, the requirements for the venting force parameters are matched perfectly by the MASCON parameter capability. A final, compelling reason for selecting existing code is to limit the size of the HOPE program. The trajectory link is the critical program link in this respect, with future trajectory modifications of HOPE being severely restricted in size. There are currently only 4,000 words of unused core remaining in the TRAJ link with which to add subroutines or improve present capability.

3.3 CODE MODIFICATIONS

The following pages describe which subroutines have been modified in HOPE/MDC 2.0 to create the HOPE/VENT program. Also described are the extent of the changes and the reasons for the modifications. For partial listings of the modified routines, see Tables B-1 through B-9 in Appendix B.

Subroutine	Lines of Code	Comments
ASSIGN	2	Alter pointers in VSTR array for trajectory link to allow MASCON and Earth gravity parameters in core simultaneously.
DAUX	17	Stores off initial input value of VTAB array and calls MASACC when correction vent capability requested.
MASACC	72	Computes acceleration of correction vents in the state and variational equations.
MCNPRC	2	Writes MASCON information which has been processed by the input processor on drum.
TRAJ	14	Resets the value of the VTAB array to its initial value upon exiting TRAJ routine.
TRIGER	4	Removes code which would branch around MASCON capability if the central body is not the Moon.
TRAJRD	2	Reads trajectory information from drum into VSTR array. Changes allow TRAJRD to read Earth gravity parameters and MASCON parameters simultaneously.
TRJSUP	2	Supervisory routine which initializes VSTR array for routines in TRAJ link. Changed TRJSUP to initialize MASCON variables when Moon is not the central body.
HOPE	4	Change the map to reduce program run time.

4.0 RESULTS

Program verification was accomplished in two distinct phases. First the solve for capability was tested using the HOPE dummy data capability. The current venting logic in HOPE/MDC 2.0 was used to generate a trajectory data tape which contained known vents. HOPE/VENT was then used to solve for the known vents. Secondly, the consider capability was tested by comparing answers with the IGS Burn model in HOPE. The consider test phase was a more involved one because the IGS Burn model and the venting logic use different methods to achieve the same goal. The differences in the way the trajectories are integrated is a prime example.

In addition to the above verification efforts, other runs were made to test program flags and pointers. The HOPE program was run with a checkmode print of the input processor, and program flow and flags were examined.

The pointers for the VSTR array were examined to ensure that using MASCON subroutines to solve for vent forces does not present hidden pitfalls. Special attention was given to routines which either read or write MASCON information on a drum. The MCNPRC and TRAJRD programs were examined to ensure proper input-output of MASCON parameters. Using COMGEN CCREF, all variables which relate to the proper functioning of the MASCON routines were traced to their occurrence in the HOPE code and studied to see if their occurrence would cause any problems in solving for or considering vent forces. The input, trajectory, differential correction (DC), and covariance propagation links of the program were dumped using checkmode print. In addition, snapshot core dumps of HOPE were made during various links to determine whether key flags had the correct values.

Two stand-alone checkcases were also employed for verification ("stand-alone" in the sense that no external comparisons were required). The two cases studied were:

1. Doing a DC run starting with the exact values of the solve for variables.
2. Closure tests on the integration of the vent force variational equations.

Test #1 produced excellent trajectory agreement between the dummy data and DC runs (to fifteen digits). Exact agreement was not obtained because observation computations are supervised by different routines in the DUMDAT and DC processors. OBCOMP is the supervisor in the DC mode while DUMCAL supervises in the DUMDAT mode, and differences in the order of the arithmetical computations give slightly different answers.

The second test was designed to examine how discontinuities in the variational equations affected integration performance. At first, discontinuous forcing functions in the variational equations were evaluated at their exact values. This was found to be inadequate for the propagation of covariance matrices and a smoothing scheme had to be adopted in the variational equations, similar to the scheme for smoothing vent discontinuities in the state equations. Performance of the integrator improved considerably. For further discussion of this point, see the results of the consider test case (Section 4.2). See also Figure 3-1 for a flowchart of the variational equations smoothing logic.

4.1 SOLVE FOR VARIABLES

Dummy data with known vents were generated using HOPE/MDC 2.0. Two distinct tapes were created, one with noisy data and one with perfect data. The perfect data were used as a checkcase for one of the stand-alone tests of the HOPE/VENT program. The on-off times of the vents were input to HOPE/VENT

and the program was executed to solve for the unknown vents as well as other selected parameters.

In Case I, the program was executed to solve for both the state and vents. The state was perturbed by 500 meters and the program was required to solve for a 20 lb_f vent. Perfect data were used in Case I. Due to the formulation of the HOPE iteration stopping rule, however, perfect data will cause more iterations than are normal. This explains why seven iterations were required in Case I. Case I results are given in Table 4-1.

In Case II, only vents were solved for and again, perfect data were used. The final iteration produced deltas in the solved for variables of 10^{-4} lb_f, clearly an insignificant correction. Case II results are given in Table 4-2.

In Case III (Table 4-3), vents and drag were solved for and the state was fixed at the exact, true value. The program was able to determine drag to within 98% of the true value.

In Case IV (Table 4-4), two contiguous vents on the timeline were solved for and the program did an excellent job in the solution for each.

Finally, in Case V (Table 4-5), SWCO data were used to test the program in a non-HOPE generated environment. The vent being solved for was a small vent, extending for 4-1/2 hrs. The program was not very successful at solving for this small vent, making an error of 50% in magnitude. Detailed studies will have to be performed to determine the feasibility of solving for small vents.

In all the cases in this section, the vehicle attitude was Inertial Hold. Additional studies will have to be performed using different attitude modes.

TABLE 4-1.- CONVERGENCE RESULTS - SOLVE FOR CAPABILITY

Case I - Solve for State and Vent

	Iteration					True Value
	#0 (initial)	#1	#3	#5	#7 (final)	
X	-2806400.	-2806399.8	-2805968.7	-2806073.3	-2806083.4	-2806084.5
Y	2878400.	2876877.5	2878177.4	2878115.3	2878110.3	2878109.7
Z	5259600.	5259190.3	5259148.9	5259323.7	5259340.4	5259342.2
$\dot{X}$	-7.04	-7.7035	-7.188	-7.054	-7.0413	-7.04
$\dot{Y}$	-6810.	-6810.19	-6809.98	-6809.99	-6810.00	-6810.
$\dot{Z}$	3720.	3720.13	3720.32	3720.03	3720.	3720.
VENT1-X	0.0	-1.7369	-.095	-.0065	-.00059	0.0
VENT2-Y	0.0	-8.9178	-19.125	-19.915	-19.99	-20.0
VENT3-Z	0.0	.0267	-.469	-.0437	-.00416	0.0

State Coordinate System: MOF50 Cartesian
Vent Coordinate System: Body
Units: State - meters, seconds; Vents-lb force
State RSS Position Error (Final - True): 1.99 meters

Vehicle Attitude - Inertial Hold

TABLE 4-2.- CONVERGENCE RESULTS - SOLVE FOR CAPABILITY

Case II - Solve for Vent, State Fixed at True Value

	Iteration					True Value
	#0 (initial)	#1	#3	#5	#7 (final)	
VENT1-X	0.0	-1.717	-.01758	.804 D-5	.113 D-8	0.0
VENT2-Y	0.0	-6.874	-20.193	-20.00	-20.0	-20.
VENT3-Z	0.0	7.709	-.0168	.1196 D-4	.2628 D-8	0.0

Units: Vents - lb force

Vehicle Attitude - Inertial Hold

TABLE 4-3.- CONVERGENCE RESULTS - SOLVE FOR CAPABILITY

Case III - Solve for Vent and Drag, State Fixed at True Value

	Iteration					True Value
	#0 (initial)	#1	#2	#3	#5 (final)	
VENT1-X	0.0	-2.384	.01588	.02249	.23	0.0
VENT1-Y	0.0	-18.8	-19.989	-19.99	-19.99	-20.0
VENT1-Z	0.0	.02976	.611 D-3	.012	.0127	0.0
DRAG	500	3889	1385	995	983	1000.

Units: Vents - lb force
Drag - Area (ft^2)

Vehicle Attitude - Inertial Hold

TABLE 4-4.- CONVERGENCE RESULTS - SOLVE FOR CAPABILITY

Case IV - Solve for 2 Vents, State Fixed at True Value

	Iteration					True Value
	#0 (initial)	#1	#2	#3	#4 (final)	
VENT1-X	0.0	-3.23	.065	.0285	.0285	0.0
VENT1-Y	0.0	-46.54	-50.035	-49.99	-49.99	-50.0
VENT1-Z	0.0	1.66	.0607	.011	.011	0.0
VENT2-X	0.0	-39.89	-30.01	-29.97	-26.975	-30.
VENT2-Y	0.0	-18.75	-20.164	-19.99	-19.996	-20.
VENT2-Z	0.0	-6.705	-.0417	.0269	.0269	0.0

Units: Vents - lb force

Vehicle Attitude - Inertial Hold

TABLE 4-5.- CONVERGENCE RESULTS - SOLVE FOR CAPABILITY

Case V - Solve for Vent, SWCO Data Tape, State Fixed at True Value

	Iteration			True Value
	#0 (initial)	#1	#2 (final)	
VENT1-X	0.0	-.1335	-.13586	0.0
VENT1-Y	0.0	-.4936	-.4939	-.5
VENT1-Z	0.0	.1805	.1805	0.0

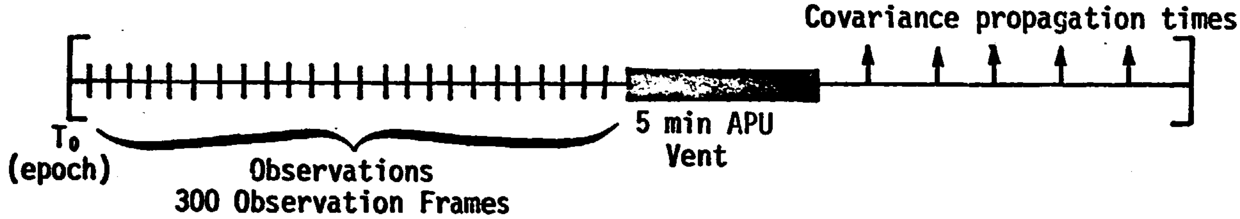
Units: Vents - lb force   Vehicle Attitude - Inertial Hold

4.2 CONSIDER VARIABLES

The consider capability was tested by matching answers obtained with the HOPE/B8.02 program running in the IGS Burn mode. HOPE/VENT was first modified so that the DOPPLER, JACHIA and TRAJ subroutines agreed with the subroutines in B8.02. Initially, discontinuous functions in the variational equations were evaluated at their true values. However, because the HOPE integration accuracy criterion applies only to the state equations, the integrator in the auto mode could not respond adequately to jumps in the variational functions. The propagated covariance matrices were not in agreement between this initial form of the HOPE/VENT program and B8.02. To substantiate the idea that integrator inaccuracy was the cause of the lack of agreement, the epoch was moved to the center of the integration time period and closure results were observed. Closure of the variational equations was poor and errors in propagated covariance matrices could be attributed to the errors in the variational equations. The integration model was changed in order to smooth the variational discontinuities and immediate improvement was observed in the results.

The following is a description of the consider test case:

1. 5 min APU vent
2. Inertial Hold Attitude
3. Observations precede beginning of vent, i.e.,



4. Consider the uncertainties in APU vent components upon the state covariance matrix.
5. Start with the exact state and do a one-iteration DC run.

APU VENT DEFINITION

Force, Body Coordinates	Value	Uncertainties
Fx	2.85 lb_f	σF_x = 1.43 lb_f
F_y	2.28 lb_f	σF_y = .52 lb_f
F_z	17.17 lb_f	σF_z = 7.25 lb_f

Tables 4-6 and 4-7 give the IGS Burn values of the state and covariance matrix at two comparison time points. Tables 4-8 and 4-9 give the HOPE/VENT values of the state and covariance matrix, with variational equation smoothing, at the same time points. At 2 hrs and 42 min after vent cutoff (April 1, 20 hr, 0 min), one observes a 1.3 meter RSS difference between the IGS Burn and HOPE/VENT values of the state, and a maximum deviation in the position sigmas of .2 meter. At 6 hrs and 42 min after vent cutoff (April 2, 0 hr, 0 min), one observes a 3.6 meter RSS difference in state values and a maximum deviation in position sigmas of .5 meter. Of course,

since the variance is the square of the sigmas, the observed differences in the covariance matrix along the diagonals is much greater.

To account for the deviation in the propagated covariance matrices between IGS Burn and HOPE/VENT, the integrator was modified to function like the integrator in the IGS Burn model. The integrator will integrate to vent discontinuities, stop, and restart in the Runge-Kutta mode. This ensures that no difference table entry will ever straddle a vent boundary. The modified integrator was checked out on a rigorous vent timeline and the value of the vent force assigned at each time point was carefully examined. Tables 4-10 and 4-11 give the values of the state and covariance matrix for the modified integrator. The agreement with the IGS Burn model is excellent. The state position differences are on the order of 10^{-4} meters and the covariance matrices agree to all digits.

Though the modified integrator is an unverified program change, it shows such marked superiority over the smoothing logic that the author feels it should eventually be adopted as the standard for venting. For the present, however, even though the smoothing logic did exhibit errors in propagating covariance matrices, the size of the errors does not preclude one from using this model. The author believes the errors in the smoothing scheme are acceptable and the first version of HOPE/VENT should be coded with smoothing logic for the vent force variational equations.

TITLE: IGS BURN MODEL, STATE VECTOR PRINTOUT AT TIME = 79, 4, 1, 20, 0, 0

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HOPEMDC2.0      APU CK-OUT,WEIGHT IS 193000.     FRENCH                                                  PAGE 407

                                        TRAJECTORY PROPAGATION

APRIL        1.1979     20 HR    0 MIN      .000000 SECONDS   JULIAN DATE      .244396533333333333+007
GREENWICH HOUR ANGLE  .12958079+003 DEG   GROUND ELAPSED TIME    2 DAYS  8 HRS 15 MIN    .00000 SECS

             CENTRAL BODY FOR VEHICLE SOV      IS EARTH                 MINUTES FROM EPOCH   .54000000+003
                                       UNITS ARE METERS,SECOND,DEGREE

                    MEAN OF 1950                                      EARTH    CENTERED                          ELLIPSE
 X     .16165871535619280+007 ALF   .74873654206394596+002 SMA   .66609216523319004+007 TFP   .45391720855080626+004
 Y     .59804033699370005+007 DLT  -.21511385441592576+002 ECC   .58097637211959300-003 PER   .66570518142353590+007
 Z    -.24417151605000349+007 BTA   .90028224990033017+002 INC   .38055154595480085+002 APO   .66647914904284490+007
 XD   -.67177000000043339+004 AZ    .12218076486330082+003 NOD   .22443383316374027+003 ALT   .28357652796277660+006
 YD    .25676365223173370+003 R     .66588701306777790+007 OMG   .27451687314033610+003 LAT  -.21603151577599630+002
 ZD   -.38329070467571670+004 V     .77381459999977040+004 TA    .30196608603799740+003 LON   .30560434666287340+003

              EARTH                                 EARTH                                 EARTH                                 EARTH
              GGRAPR                                GGRAPI                                GGRAPR                                MOF50
              XYZ                                   SET1                                  KEPLER                                UVW1
 X     .36074475296760116+007 TFP   .45391720855080636+004 SMA   .66609216523319004+007 U     .66588701306777700+007
 Y    -.50382932150043551+007 PER   .66570518142353690+007 ECC   .58097637211181000-003 V     .00000000000000000
 Z    -.24374294304844401+007 APO   .66647914904284390+007 INC   .38171420074967070+002 W    -.27660881397884030-011
 XD    .40632313306986980+004 ALT   .28357652942766740+006 NOD   .95580478861879760+002 UD   -.38119576877358740+001
 YD    .47779366215785010+004 LAT  -.21603151577599630+002 OMG   .27433332107986530+003 VD    .77381450610762690+004
 ZD   -.38518362517778010+004 LON   .30560434666287340+003 TA    .30198608603799810+003 WD    .00000000000000000

              EARTH                                 EARTH                                 EARTH                                 EARTH
              MOF50                                 TOFD                                  TOFD                                  TOFD
              SET2                                  XYZ                                   KEPLER                                SPHER
 M     .30204254036273670+003 X     .15844884653280950+007 SMA   .66609216523319004+007 ALF   .75185085085164530+002
 EA    .30201431537488680+003 Y     .59907333016821310+007 ECC   .58097637211181000-003 DLT  -.21471753657948840+002
 PRD   .54101715255894840+004 Z    -.24374294304844701+007 INC   .38171420074967070+002 BTA   .90028224990033017+002
 EGY  -.29921015111421983+008 XD   -.67082867785122990+004 NOD   .22516121524961600+003 AZ    .12223499510024417+003
 SLR   .66609194040474060+007 YD    .20285340521639830+003 OMG   .27433332107986540+003 R     .66588701306777700+007
 TF    .27860827914491370+005 ZD   -.38518362517778010+004 TA    .30198608603799800+003 V     .77381459999977040+004
```

Table 4-6

TITLE: IGS BURN MODEL, COVARIANCE MATRIX PRINTOUT AT TIME = 79, 4, 1, 20, 0, 0

HOPEMDC2.0 APU CK-OUT,WEIGHT IS 193000. FRENCH PAGE 908

COVARIANCE PROPAGATION

NORMALIZED COVARIANCE MATRIX - CARTESIAN ELEMENTS

FRAME- MEAN OF 1950 BODY- EARTH

	1 STATE1 X	2 STATE1 Y	3 STATE1 Z	4 STATE1 XDOT	5 STATE1 YDOT	6 STATE1 ZDOT
1 STATE1 X	.96657069+006	-.85297207+000	.99794353+000	.99200228+000	.99920418+000	-.99479232+000
2 STATE1 Y	-.64268524+005	.58734518+004	-.88343728+000	-.78027241+000	-.87300178+000	.90105351+000
3 STATE1 Z	.57484727+006	-.39668285+005	.34327485+006	.98221651+000	.99968373+000	-.99923709+000
4 STATE1 XDOT	.25242900+003	-.15477507+002	.14874855+003	.66990944-001	.98621071+000	-.97415687+000
5 STATE1 YDOT	.11406344+004	-.79047149+002	.69200303+003	.30157973+000	.13958822+001	-.99805965+000
6 STATE1 ZDOT	-.51401485+003	.36293071+002	-.30769184+003	-.13251449+000	-.61973684+000	.27621857+000
7 V1 I 1 BIAX	.78834605+000	-.67195115-001	.48206220+000	.19381056-003	.96386936-003	-.43864502-003
8 V1 I 1 BIAY	-.10778560+000	.17061744-001	-.72808071-001	-.20060053-004	-.14090022-003	.70189595-004
9 V1 I 1 BIAZ	.59200719+000	-.61109426-001	.37233542+000	.13688808-003	.73691397-003	-.34456284-003

	7 V1 I 1 BIAX	8 V1 I 1 BIAY	9 V1 I 1 BIAZ
1 STATE1 X	.90812276+000	-.40349043+000	.73478466+000
2 STATE1 Y	-.99296796+000	.51934352+000	-.97299679+000
3 STATE1 Z	.93180775+000	-.45734911+000	.77650825+000
4 STATE1 XDOT	.84803469+000	-.28524190+000	.64534807+000
5 STATE1 YDOT	.92392779+000	-.43891114+000	.76110105+000
6 STATE1 ZDOT	-.94521586+000	.49151368+000	-.80000354+000
7 V1 I 1 BIAX	.77967126-006	-.74884448+000	.94238659+000
8 V1 I 1 BIAY	-.17966277-006	.73828047-007	-.88740628+000
9 V1 I 1 BIAZ	.68192232-006	-.19759833-006	.67158376-006

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Table 4-6,

TITLE: IGS BURN MODEL, STATE VECTOR PRINTOUT AT TIME = 79, 4, 2, 0, 0, 0

HOPEMDC2.0 APU CK-OUT,WEIGHT IS 193000, FRENCH PAGE 437

TRAJECTORY PROPAGATION

APRIL 2,1979 0 HR 0 MIN .000000 SECONDS JULIAN DATE .2443965500000000+007
GREENWICH HOUR ANGLE .1897950l+003 DEG GROUND ELAPSED TIME 2 DAYS 12 HRS 15 MIN .00000 SECS

CENTRAL BODY FOR VEHICLE SOV IS EARTH MINUTES FROM EPOCH .78000000+003
UNITS ARE METERS,SECOND,DEGREE

MEAN OF 1950				EARTH CENTERED		ELLIPSE	
X	.4182914812842702+007	ALF	.3225741796422960+003	SMA	.6656021953410682+007	TFP	.1176544154131433+004
Y	-.3201067811918359+007	DLT	.3767887863487779+002	ECC	.6467553939329722-003	PER	.6651717135310177+007
Z	.4067867257229948+007	RTA	.8996369900517282+002	INC	.3803050076707413+002	APO	.6660326771511187+007
XD	.5059407290637632+004	AZ	.9559203503022917+002	NOD	.2234735781154640+003	ALT	.2850470482813727+006
YD	.5834579067683087+004	R	.6655157201382207+007	OMG	.1874340727338965+002	LAT	.3799595475285576+002
ZD	-.5939005879012231+003	V	.7739615275107724+004	TA	.7844787731765419+002	LON	.1331279491995970+003

EARTH GGRAPR XYZ		EARTH GGRAPI SET1		EARTH GGRAPR KEPLER		EARTH MOFSO UVWI	
X	-.3594491049454702+007	TFP	.1176544154131429+004	SMA	.6656021953410682+007	U	.6655157201382207+007
Y	.3837392161348023+007	PER	.6651717135310186+007	ECC	.6467553939316312-003	V	.3457610174735504-012
Z	.4077258431954764+007	APO	.6660326771511170+007	INC	.3814443483996422+002	W	.0000000000000000
XD	-.5654897042457643+004	ALT	.2850470482813727+006	NOD	.3424953490403452+002	UD	.4903602283747901+001
YD	-.4671879265373265+004	LAT	.3799595475285576+002	OMG	.1855574343617219+002	VD	.7739613721715410+004
ZD	-.5798873682003790+003	LON	.1331279491995970+003	TA	.7844787731765389+002	WD	-.7923689983768863-014

EARTH MOFSO SET2		EARTH TOFD XYZ		EARTH TOFD KEPLER		EARTH TOFD SPHER	
M	.7837527297281767+002	X	.4192146679688959+007	SMA	.6656021753410682+007	ALF	.3228729621798882+003
FA	.7841157396470987+002	Y	-.3173605562146364+007	ECC	.6467553939329722-003	DLT	.3780943228884763+002
PTD	.5594203179669426+004	Z	.4079858431954764+007	INC	.3814453483996422+002	BTA	.8996369900517282+002
EGY	-.2994304667773190+008	XD	.5013936662368662+004	NOD	.2239945459250711+003	AZ	.9547010478403762+002
SLR	.6656019169246356+007	YD	.5867351565454290+004	OMG	.1855594343617199+002	R	.6655157201382207+007
TF	.4562345564586857+005	ZD	-.5798873682003790+003	TA	.7844787731765410+002	V	.7739615275107724+004

Table 4-7

TITLE: IGS BURN MODEL, COVARIANCE MATRIX PRINTOUT AT TIME = 79, 4, 2, 0, 0, 0

HOPEMDC2.0 APU CK-OUT,WEIGHT IS 193000, FRENCH PAGE 432

COVARIANCE PROPAGATION

NORMALIZED COVARIANCE MATRIX - CARTESIAN ELEMENTS

FRAME- MEAN OF 1950 BODY- EARTH

	1 STATE1 X	2 STATE1 Y	3 STATE1 Z	4 STATE1 XDOT	5 STATE1 YDOT	6 STATE1 ZDOT
1 STATE1 X	.29791922+007	-.99999256+000	-.99985006+000	-.99971488+000	.99962889+000	-.99987371+000
2 STATE1 Y	.36332877+007	.45066939+007	-.99990940+000	-.99979914+000	.99972596+000	-.99992614+000
3 STATE1 Z	-.42758222+006	-.60482360+006	.81185430+005	.99997758+000	-.99994941+000	.99990044+000
4 STATE1 XDOT	-.32054074+004	-.39762614+004	.53378018+003	.35096699+001	-.99999431+000	.99994938+000
5 STATE1 YDOT	.26764118+004	.33200926+004	-.44571503+003	-.29306966+001	.24472616+001	-.99991297+000
6 STATE1 ZDOT	-.32764538+004	-.40642640+004	.54553153+003	.35867088+001	-.29949348+001	.36658098+001
7 V1 I 1 BIAX	-.14025698+001	-.17370327+001	.23186106+000	.15204536-002	-.12678655-002	.15588962-002
8 V1 I 1 BIAY	.20865153+000	.25684164+000	-.33555112-001	-.21782125-003	.18066176-003	-.22601145-003
9 V1 I 1 BIAZ	-.10778394+001	-.13326820+001	.17684748+000	.11560678-002	-.96251207-003	.11907992-002

	7 V1 I 1 BIAX	8 V1 I 1 BIAY	9 V1 I 1 BIAZ
1 STATE1 X	-.92810000+000	.44868024+000	-.76847550+000
2 STATE1 Y	-.92666596+000	.44527233+000	-.76603286+000
3 STATE1 Z	.92158310+000	-.43342001+000	.75737287+000
4 STATE1 XDOT	.91914551+000	-.42791393+000	.75300882+000
5 STATE1 YDOT	-.91786167+000	.42502584+000	-.75078553+000
6 STATE1 ZDOT	.92209670+000	-.43444499+000	.75893307+000
7 V1 I 1 BIAX	.77967126-006	-.74884448+000	.94238649+000
8 V1 I 1 BIAY	-.17966277-006	.73828047-007	-.88740628+000
9 V1 I 1 BIAZ	.68192232-006	-.19759833-006	.67158376-006

Table 4-7

TITLE: VENTING SMOOTHING LOGIC STATE VECTOR PRINTOUT AT TIME = 79, 4, 1, 20, 0, 0

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HOPEMOC7.0        CONSIDER APU VENT FORCE 8/15/78  LVZ.                                                   PAGE 112

                                        TRAJECTORY PROPAGATION

APRIL       1,1979     20 HR    0 MIN         .000000 SECONDS   JULIAN DATE      .2443965333333333+007
GREENWICH HOUR ANGLE  .22616105+001 DEG      GROUND ELAPSED TIME    2 DAYS   8 HRS 15 MIN     .00000 SECS

              CENTRAL BODY FOR VEHICLE SOV    IS EARTH                    MINUTES FROM EPOCH  .54000000+003
                                         UNITS ARE METERS,SECOND,RADIAN

                   MEAN OF 1950                                  EARTH   CENTERED                        ELLIPSE
X     .1616588333126985+007 ALF  .1306791636809067+001 SMA  .6660921730544955+007 TFP  .4539161709251426+004
Y     .5980903411675569+007 DLT -.3754444023174964+000 ECC  .5809801413773533-003 PER  .6657051867296240+007
Z    -.2441714562979139+007 BTA  .1571280952745753+001 INC  .6641877478927405+000 APO  .6664791593793671+007
XD   -.6717706445861977+004 AZ   .2132456697306274+001 NOD  .3920766675736808+001 ALT  .2835766328681389+006
YD    .2467651741235936+003 R    .6658870235426387+007 OMG  .4791235250499423+001 LAT -.3770460201780045+000
ZD   -.3832809560172525+004 V    .7738145923711789+004 TA   .5270639339222877+001 LON  .5333801875999890+001

              FARTH                            EARTH                            EARTH                            EARTH
              GGRAPR                           GGRAPI                           GGRAPR                           MOF50
              XYZ                              SETI                             KEPLER                           UVWI
X     .3607441817471874+007 TFP  .4539161709251436+004 SMA  .6660921730544955+007 U    .6658870235426387+007
Y    -.5038294754138815+007 PER  .6657051867296240+007 ECC  .5809801413773533-003 V   -.1383044069894201-011
Z    -.2437428429626212+007 APO  .6664791593793671+007 INC  .6662169633096741+000 W    .0000000000000000
XD    .4063232714904886+004 ALT  .2835766328681390+006 NOD  .1668194053476751+001 UD  -.3812011339352541+001
YD    .4777935505022551+004 LAT -.3770460201780045+000 OMG  .4788031662696173+001 VD   .7738144984763914+004
ZD   -.3851836761975247+004 LON  .5333801875999890+001 TA   .5270639339222888+001 WD   .2881341812279586-014

              EARTH                            EARTH                            EARTH                            EARTH
              MOF50                            TOFD                             TOFD                             TOFD
              SETZ                             XYZ                              KEPLER                           SPHER
M     .5271624666943158+001 X    .1584489642898516+007 SMA  .6660921730544955+007 ALF  .1312227101454807+001
EA    .5271132041035591+001 Y    .5990733351126705+007 ECC  .5809801413743675-003 DLT -.3747526943571022+000
PRD   .5410171618879456+004 Z   -.2437428829626212+007 INC  .6667169633096741+000 BTA  .1571288952745753+001
ESY  -.7992101476298498+008 XD  -.6708286357508091+004 NOD  .3929804550601572+001 AZ   .2135409552228056+001
SLR   .6660919482231258+007 YD   .2028547298542608+003 ONG  .4788031662696169+001 R    .6658870235426387+007
TF    .2786083829074857+005 ZD  -.3851836761975247+004 TA   .5270639339222893+001 V    .7738145923711789+004
```

Table 4-8

TITLE: VENTING SMOOTHING LOGIC COVARIANCE MATRIX PRINTOUT AT TIME = 79, 4, 1, 20, 0, 0

COVARIANCE PROPAGATION

NORMALIZED COVARIANCE MATRIX - CARTESIAN ELEMENTS

FRAME- MEAN OF 1950 BODY- EARTH

	1 STATE1 X	2 STATE1 Y	3 STATE1 Z	4 STATE1 XDOT	5 STATE1 YDOT	6 STATE1 ZDOT
1 STATE1 X	.96709838+006	-.85318896+000	.99796768+000	.99202497+000	.99920560+000	-.99480190+000
2 STATE1 Y	-.64286089+005	.58704711+004	-.88360162+000	-.78064475+000	-.87318706+000	.90119267+000
3 STATE1 Z	.57015271+006	-.39675677+005	.34344930+006	.98726249+000	.99968445+000	-.99973825+000
4 STATE1 XDOT	.25258571+003	-.15486054+002	.14904238+003	.67035013-001	.98624637+000	-.97421879+000
5 STATE1 YDOT	.11612685+004	-.79065353+002	.69236763+003	.30177184+000	.13966413+001	-.99806328+000
6 STATE1 ZDOT	-.51428773+003	.36298473+002	-.30784681+003	-.13259941+000	-.62006149+000	.27635572+000
7 MC 1 MASS	-.77759360+003	.61767519+001	-.41799330+003	-.24013371+000	-.87866478+000	.35034327+000
8 MC 1 LATUDE	.49112086+002	.15400935+001	.29642890+002	.16921096-001	.55786692-001	-.24047743-001
9 MC 1 LGTUDE	.59910304+004	-.55418850+003	.36593379+004	.14091340+001	.72774328+001	-.33553825+001

	7 MC 1 MASS	8 MC 1 LATUDE	9 MC 1 LGTUDE
1 STATE1 X	-.55294421+000	.96031460-001	.82766486+000
2 STATE1 Y	.56375142-001	.38655142-001	-.99766107+000
3 STATE1 Z	-.49877182+000	.97271550-001	.86125775+000
4 STATE1 XDOT	-.64858401+000	.12568235+000	.75069483+000
5 STATE1 YDOT	-.51992983+000	.90778880-001	.84937163+000
6 STATE1 ZDOT	.46604034+000	-.87970435-001	-.88037924+000
7 MC 1 MASS	.20449000+001	.00000000	.00000000
8 MC 1 LATUDE	.00000000	.2704[illegible]+000	.00000000
9 MC 1 LGTUDE	.00000000	.00000000	.52562500+002

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Table 4-8

TITLE: VENTING SMOOTHING LOGIC STATE VECTOR PRINTOUT AT TIME = 79, 4, 2, 0, 0, 0

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HOPEMDC2.0    CONSIDER APU VENT FORCE 8/15/78  LVZ                                          PAGE 136

                                      TRAJECTORY PROPAGATION

APRIL       2,1979      0 HR   0 MIN       .000000 SECONDS   JULIAN DATE      .2443965500000000+007
GREENWICH HOUR ANGLE   .33116752+001 DEG   GROUND ELAPSED TIME    2 DAYS 12 HRS 15 MIN    .00000 SECS

            CENTRAL BODY FOR VEHICLE SOV     IS EARTH              MINUTES FROM EPOCH  .78000000+003
                                     UNITS ARE METERS,SECOND,RADIAN

                   MEAN OF 1950                                     EARTH   CENTERED             ELLIPSE
X     .4182912870516357+007 ALF  .5429980937756438+001 SMA  .6656022029620890+007 TFP  .1176550986797326+004
Y    -.3201070165265424+007 DLT  .6576196651260653+000 ECC  .4467614551414595-003 PER  .6651717171127559+007
Z     .4067862883773594+007 BTA  .1570162747945827+001 INC  .6637574572129443+000 APO  .6660326881114721+007
XD    .5050409520450548+004 AZ   .1668395397581465+001 NOD  .3900349727449716+001 ALT  .2850471507701943+006
YD    .5834577264555636+004 R    .6655157302909273+007 OMG  .3271257763960364+000 LAT  .6631545593301216+000
ZD   -.5938083790421494+003 V    .7739615201349222+004 TA   .1369181684819021+001 LON  .2323520459890738+001

             EARTH                      EARTH                      EARTH                      EARTH
             GGRAPR                     GGRAPI                     GGRAPR                     MOFSO
             XYZ                        SET1                       KEPLER                     UVWI
X    -.3594478739981113+007 TFP  .1176550986797320+004 SMA  .6656022029620890+007 U    .6655157302909273+007
Y     .3837394166865064+007 PER  .6651717171127550+007 ECC  .6467614551428006-003 V    .1037283052420651-011
Z     .4079858738044786+007 APO  .6660326888114230+007 INC  .6657459819112843+000 W    .0000000000000000
XD   -.5654893796486154+004 ALT  .2850471507701943+006 NOD  .5977671508612659+000 UD   .4903656163441325+001
YD   -.4671897292191047+004 LAT  .6631545593301216+000 OMG  .3238539152131337+000 VD   .7739613647922756+004
ZD   -.5798851529418473+003 LON  .2323520459890738+001 TA   .1369181684819018+001 WD  -.4322012718419380-014

             EARTH                      EARTH                      EARTH                      EARTH
             MOFSO                      TOFD                       TOFD                       TOFD
             SET2                       XYZ                        KEPLER                     SPHER
M     .1367014486012463+001 X    .4192144771867180+007 SMA  .6656022029620890+007 ALF  .5635195675636197+001
EA    .1368548064813798+001 Y   -.3173608926092328+007 ECC  .6467614551401184-003 DLT  .6598991281278071+000
PRD   .5404203722485100+004 Z    .4079858738044786+007 INC  .6657459819112843+000 BTA  .1570162747945827+001
EGY  -.2994304053488968+008 XD   .5013938897618796+004 NOD  .3909442331015018+001 AZ   .1666267311579967+001
SLR   .6656019245404347+007 YD   .5867349776969051+004 OMG  .3238539152131323+000 R    .6655157302909273+007
TF    .4562344901320267+005 ZD  -.5798851529418473+003 TA   .1369181684819019+001 V    .7739615201349222+004
```

Table 4-9

TITLE: VENTING SMOOTHING LOGIC COVARIANCE MATRIX PRINTOUT AT TIME = 79, 4, 2, 0, 0, 0

COVARIANCE PROPAGATION

NORMALIZED COVARIANCE MATRIX - CARTESIAN ELEMENTS

FRAME- MEAN OF 1950 BODY- EARTH

	1 STATE1 X	2 STATE1 Y	3 STATE1 Z	4 STATE1 XDOT	5 STATE1 YDOT	6 STATE1 ZDOT
1 STATE1 X	.29309134+007	.99999254+000	-.99985000+000	-.99971545+000	.99962933+000	-.99987393+000
2 STATE1 Y	.36353862+007	.45972530+007	-.99990941+000	-.99979969+000	.99972643+000	-.99992634+000
3 STATE1 Z	-.48785138+006	-.60515156+006	.81227370+005	.99997774+000	-.99994959+000	.99999044+000
4 STATE1 XDOT	-.32073092+004	-.39785813+004	.53407773+003	.35117685+001	-.99999429+000	.99994949+000
5 STATE1 YDOT	.26779692+004	.33219832+004	-.44595728+003	-.29324081+001	.24486567+001	-.99991302+000
6 STATE1 ZDOT	-.32783787+004	-.40666115+004	.54583254+003	.35888341+001	-.29966675+001	.36479614+001
7 MC 1 MASS	.12489298+004	.15589226+004	-.21382534+003	-.14211364+001	.11930784+001	-.14305529+001
8 MC 1 LATUDE	-.80472763+002	-.10059632+003	.13796274+002	.90093583-001	-.75263961-001	.96194660-001
9 MC 1 LGTUDE	-.10616179+005	-.13137090+005	.17485250+004	.11449742+002	-.95403408+001	.11764154+002

	7 MC 1 MASS	8 MC 1 LATUDE	9 MC 1 LGTUDE
1 STATE1 X	.51015307+000	-.90394369-001	-.85532023+000
2 STATE1 Y	.51337676+000	-.91101692-001	-.85331400+000
3 STATE1 Z	-.52465274+000	.93023450-001	.84621873+000
4 STATE1 XDOT	-.53031857+000	.92454399-001	.84274222+000
5 STATE1 YDOT	.53317406+000	-.92495323-001	-.84093403+000
6 STATE1 ZDOT	-.52234268+000	.96590684-001	.84724752+000
7 MC 1 MASS	.20449000+001	.00000000	.00000000
8 MC 1 LATUDE	.00000000	.27049000+000	.00000000
9 MC 1 LGTUDE	.00000000	.00000000	.52562500+002

Table 4-9

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TITLE: EXACT INTEGRATOR, STATE VECTOR PRINTOUT AT TIME = 79, 4, 1, 20, 0, 0

HOPEMOC2.0 CONSIDER APU VENT FORCE 8/15/78 LVZ . PAGE 104

TRAJECTORY PROPAGATION

APRIL 1,1979 20 HR 0 MIN .000000 SECONDS JULIAN DATE .2443965333333333+007
GREENWICH HOUR ANGLE .22616105+001 DEG GROUND ELAPSED TIME 2 DAYS 8 HRS 15 MIN .00000 SECS

CENTRAL BODY FOR VEHICLE SOV IS EARTH MINUTES FROM EPOCH .54000000+003
UNITS ARE METERS,SECOND,RADIAN

MEAN OF 1950				EARTH CENTERED		ELLIPSE	
X	.1616587153643511+007	ALF	.1306791788841242+001	SMA	.6660921652334557+007	TFP	.4539172117320001+004
Y	.5983403367027883+007	DLT	-.3754445029590737+000	ECC	.5809763716896268-003	PER	.6657051814240874+007
Z	-.2441715160394281+007	BTA	.1571288945795757+001	INC	.6641877450466088+000	APO	.6664791490428239+007
XD	-.6717706894194812+004	AZ	.2132456629474132+001	NOD	.3920766679026581+001	ALT	.2835765295104192+006
YD	.2567438529479897+003	R	.6658870130560679+007	OMG	.4791223251594336+001	LAT	-.3770461730262323+000
ZD	-.3832809048913111+004	V	.7738146030135272+004	TA	.5272651533538897+001	LON	.5333802057656014+001

EARTH GGRAPR XYZ		EARTH GGRAPI SETI		EARTH GGRAPR KEPLER		EARTH MOFSO UVWI	
X	.3607642529534185+007	TFP	.4539172117320012+004	SMA	.6660921652334557+007	U	.6658870130561679+007
Y	-.5038293815042557+007	PER	.6657051814240865+007	ECC	.5809763716911198-003	V	.0000000000000000
Z	-.2437429430378097+007	APO	.6664791490428249+007	INC	.6662169604700535+000	W	.0000000000000000
XD	.4963231330906927+004	ALT	.2835765295104192+006	NOD	.1648194056772763+001	UD	-.3811957596925106+001
YD	.4777936621497743+004	LAT	-.3770461238262323+000	OMG	.4788019663790304+001	VD	.7738145061213881+004
ZD	-.3851036251933930+004	LON	.5333802057656014+001	TA	.5270651533538907+001	WD	-.2881341812279586-014

EARTH MOFSO SET2		EARTH TOFD XYZ		EARTH TOFD KEPLER		EARTH TOFD SPHER	
M	.5271636847359100+001	X	.1584483465410086+007	SMA	.6660921652334557+007	ALF	.1312227283110930+001
EA	.5271144228491578+001	Y	.5990733391573547+007	ECC	.5809763716926127-003	DLT	-.3747527974981052+000
PRD	.5410171523592716+004	Z	-.2437429430378097+007	INC	.6662169604700535+000	BTA	.1571288945795757+001
EGY	-.2992101511420791+008	XD	-.6708286778574751+004	NOD	.3929604553097584+001	AZ	.2135409484652723+001
SLR	.6660919404050062+007	YD	.2028534054342439+003	OMG	.4788019663790307+001	R	.6658870130560679+007
TF	.2786082720268000+005	ZD	-.3851836251933930+004	TA	.5270651533538905+001	V	.7738146000135272+004

Table 4-10

TITLE: EXACT INTEGRATOR, COVARIANCE MATRIX PRINTOUT AT TIME = 79, 4, 1, 20, 0, 0

COVARIANCE PROPAGATION

NORMALIZED COVARIANCE MATRIX - CARTESIAN ELEMENTS

FRAME- MEAN OF 1950

BODY- EARTH

	1 STATE1 X	2 STATE1 Y	3 STATE1 Z	4 STATE1 XDOT	5 STATE1 YDOT	6 STATE1 ZDOT
1 STATE1 X	.96657070+006	-.85297207+000	.99796353+000	.99200228+000	.99920418+000	-.99479232+000
2 STATE1 Y	-.64768525+005	.58734519+004	-.88343728+000	-.78027241+000	-.87300178+000	.70105351+000
3 STATE1 Z	.57484728+006	-.39668285+005	.34327486+006	.98271651+000	.99968373+000	-.99923709+000
4 STATE1 XDOT	.25242800+003	-.15477507+002	.14494855+003	.66990945-001	.98621071+000	-.97415682+000
5 STATE1 YDOT	.11606344+004	-.79047151+002	.69200304+003	.30157973+000	.13958822+001	-.99875965+000
6 STATE1 ZDOT	-.51401486+003	.36293072+002	-.30769184+003	-.13251449+000	-.61973695+000	.27621857+000
7 MC 1 MASS	-.77781559+003	.61745187+001	-.41810929+003	-.24020721+000	-.87891083+000	.35044175+000
8 MC 1 LATUDE	.49129601+002	.15400267+001	.29653328+002	.16927022-001	.55806924-001	-.24055455-001
9 MC 1 LGTUDE	.58978991+004	-.55433033+003	.36577271+004	.14079757+001	.72738966+001	-.33540328+001

	7 MC 1 MASS	8 MC 1 LATUDE	9 MC 1 LGTUDE
1 STATE1 X	-.55325302+000	.96097931-001	.82745145+000
2 STATE1 Y	.56340457-001	.38666240-001	-.99766260+000
3 STATE1 Z	-.49903704+000	.97330534-001	.86109744+000
4 STATE1 XDOT	-.64899590+000	.12576772+000	.75032446+000
5 STATE1 YDOT	-.52021682+000	.90834493-001	.84918972+000
6 STATE1 ZDOT	.46628706+000	-.88020493-001	-.88024358+000
7 MC 1 MASS	.20449000+001	.00000000	.00000000
8 MC 1 LATUDE	.00000000	.27900000+000	.00000000
9 MC 1 LGTUDE	.00000000	.00000000	.52562500+002

ORIGINAL PAGE IS OF POOR QUALITY

Table 4-10

TITLE: EXACT INTEGRATOR STATE VECTOR PRINTOUT AT TIME = 79, 4, 2, 0, 0, 0

HOPEMDC2.0 CONSIDER APU VENT FORCE 8/15/78 LVZ •

TRAJECTORY PROPAGATION

APRIL 2,1979 0 HR 0 MIN .000000 SECONDS JULIAN DATE .2443965500000000000+007
GREENWICH HOUR ANGLE .33116752+001 DEG GROUND ELAPSED TIME 2 DAYS 12 HRS 15 MIN .00000 SECS

CENTRAL BODY FOR VEHICLE SOV IS EARTH MINUTES FROM EPOCH .78000000+003
UNITS ARE METERS,SECOND,RADIAN

	MEAN OF 1950				EARTH CENTERED		ELLIPSE
X	.4182914812430385+007	ALF	.5629981516559186+001	SMA	.6656021953518130+007	TFP	.1176544125520769+004
Y	-.3201067812389460+007	DLT	.6576196179825462+000	ECC	.6467553722796192-003	PER	.6651717135561681+007
Z	.4067562572345452+007	BTA	.1570162754938953+001	INC	.6637574545676066+000	APO	.6660326771474578+007
XD	.5052407791213350+004	AZ	.1668395749886095+001	NOD	.3900349729328729+001	ALT	.2850470482774186+006
YD	.5034579067480110+004	R	.6655157201378066+007	OMG	.3271342032160627+000	LAT	.6631545128851448+000
ZD	-.5939005875769176+003	V	.7739615275174993+004	TA	.1369173717045315+001	LON	.2323521039841940+001

	FARTH GGRAPR XYZ		EARTH GGRAPI SETI		EARTH GGRAPR KEPLER		EARTH MOF50 UVWI
X	-.3594481039971543+007	TFP	.1176544125520767+004	SMA	.6656021953518130+007	U	.6655157201378066+007
Y	.3837372161765754+007	PER	.6651717135561690+007	ECC	.6467553722782781-003	V	.4149132709682604-011
Z	.4079058431999593+007	APO	.6660325771474570+007	INC	.6657459792697483+000	W	.0000000000000000
XD	-.5654822042765385+004	ALT	.2850470482774186+006	NOD	.5977671527495207+000	UD	.4903692086121741+001
YD	-.4671897265147215+004	LAT	.6631545128851440+000	OMG	.3238623420281987+000	VD	.7739613721782824+004
ZD	-.5798873678752001+003	LON	.2323521039841940+001	TA	.1369173717045310+001	WD	-.7923689983768863-014

	FAPTH MOF50 SET2		EARTH TOFD XYZ		EARTH TOFD KEPLER		EARTH TOFD SPHER
M	.1347906532224251+001	X	.4192146699280093+007	SMA	.6656021953518130+007	ALF	.5635196255587400+001
EA	.1368549104332461+001	Y	-.3173606560420138+007	ECC	.6467553722782781-003	DLT	.6598990817592556+000
PRD	.5404203129000263+004	Z	.4479858431999593+007	INC	.6657459792697483+000	BTA	.1570162754938953+001
EGY	-.2994304087724854+008	XD	.5913936662744774+004	NOD	.3909442332903273+001	AZ	.1666267665631928+001
SLR	.6656019169353990+007	YD	.5867351565253687+004	OMG	.3233623420281986+000	R	.6655157201378066+007
TF	.4362345587447923+005	ZD	-.5798873678752001+003	TA	.1369173717045310+001	V	.7739615275174993+004

Table 4-11

TITLE: EXACT INTEGRATOR, COVARIANCE MATRIX PRINTOUT AT TIME = 79, 4, 2, 0, 0, 0

COVARIANCE PROPAGATION

NORMALIZED COVARIANCE MATRIX - CARTESIAN ELEMENTS

FRAME- MEAN OF 1950 BODY- EARTH

	1 STATE1 X	2 STATE1 Y	3 STATE1 Z	4 STATE1 XDOT	5 STATE1 YDOT	6 STATE1 ZDOT
1 STATE1 X	.29791923+007	.99999256+000	-.99985006+000	-.99971488+000	.99962889+000	-.99987371+000
2 STATE1 Y	.36332873+007	.45066940+007	-.99790940+000	-.99979914+000	.99972596+000	-.99992614+000
3 STATE1 Z	-.48758223+006	-.60482361+006	.81185431+005	.99997758+000	-.99994941+000	.99999044+000
4 STATE1 XDOT	-.32054074+004	-.39742614+004	.53378019+003	.35096700+001	-.99999431+000	.99994938+000
5 STATE1 YDOT	.26764118+004	.33200927+004	-.44571503+003	-.29306967+001	.24477617+001	-.99991297+000
6 STATE1 ZDOT	-.32764537+004	-.40642641+004	.54553154+003	.35867088+001	-.29949348+001	.36658098+001
7 MC 1 MASS	.12492703+004	.15593556+004	-.21388726+003	-.14215365+001	.11934116+001	-.14309548+001
8 MC 1 LATUDE	-.80500593+002	-.10043276+003	.13790584+002	.90126062-001	-.75290778-001	.96228613-001
9 MC 1 LGTUDE	-.12610821+005	-.13130575+005	.17476931+004	.31443597+002	-.95353842+001	.11758035+002

	7 MC 1 MASS	8 MC 1 LATUDE	9 MC 1 LGTUDE
1 STATE1 X	.51044533+000	-.90457754-001	-.85513760+000
2 STATE1 Y	.51366510+000	-.91160111-001	-.85313427+000
3 STATE1 Z	-.52494019+000	.93074550-001	.84603460+000
4 STATE1 XDOT	-.53062639+000	.92515374-001	.84254172+000
5 STATE1 YDOT	.53347494+000	-.92554648-001	-.84073466+000
6 STATE1 ZDOT	-.52264275+000	.96653128-001	.84705033+000
7 MC 1 MASS	.20449000+001	.00000000	.00000000
8 MC 1 LATUDE	.00000000	.27040000+000	.00000000
9 MC 1 LGTUDE	.00000000	.00000000	.52562500+002

Table 4-11

5.0 USER'S GUIDE

The following instructions refer to HOPE version MDC 3.0 which should be the first released version incorporating the capability to solve or consider vent forces. An update to the following instructions will be published in a working paper to accommodate cosmetic changes which are likely to occur in the variable names.

As currently envisioned, the execution of the HOPE vent capability will require a separate map, distinct from the current HOPE map. This has been necessitated because of the desire to preserve the MASCON capability in its original form. The recently modified subroutines will be copied onto the PCF tape with changed element names. The original MASCON subroutines and the modified MASCON subroutines will exist on the PCF tape simultaneously and the HOPE map will determine which copy of the MASCON subroutines will be brought into core.

The capability to solve for or consider vents must be used in conjunction with the current HOPE vent capability. The rule which must be strictly observed is that any end point of a correction vent must correspond to an end point of a nominal vent in the VTAB table. The simplest way to ensure that this will occur is to input, in the $VITVTL section, a nominal vent with zeroes in all components which have the same start and stop times as the correction vent. If the user omits to enter any nominal vents while attempting to solve or consider correction vents, the program will terminate.

The following is a list of additional strict guidelines that must be followed:

1. The program is written for a maximum of 50 nominal entries in the VTAB table. If the VTAB array must exceed this size, the temporary storage array VOTAB will have to be re-dimensioned in DAUX and TRAJ.
2. If HOPE/VENT is used, the scale card for the MASCONS must be input as: SCLMC = ERADII,RADIAN,MINUTE*
3. The correction vent information is input in the $MASCON section using the MC card, i.e., MCi = x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9*
   The variable, i, is the number of the correction vent; x_1, x_2, x_3 are, respectively, the body coordinate XYZ components of the correction vent in lb_f; x_4, x_5 are zeroes; x_6, x_7 are the start and stop times of the correction vent in internal time, i.e., minutes past midnight day of epoch; x_8, x_9 are zeroes. The fields, x_8 and x_9, may be omitted if desired. Fields x_4 and x_5 must be input as zeroes. The correction vents should be listed in numerical order beginning with i = 1 and proceeding to i = N, where N is the maximum number of vents to be solved for or considered
4. To solve for or consider a correction vent, the user must specify the variables, MASi, MLTi, MLGi, on the SOLVE or CONSID cards. The variable, MASi, indicates the x component of the ith correction vent, MLTi indicates the y component of the ith vent, and MLGi indicates the z component of the ith vent. If more than one correction vent is being solved for or considered, the i-indices should be arranged in ascending numerical order on the SOLVE or CONSID cards. If correction vents are to be considered, the HOPE nominal ordering is used, with MASi, MLTi, MLGi representing the XYZ components of the ith correction vent in the consider covariance matrix.

The labels, $MASCON, MC, MAS MLT, and MLG, are temporary and are likely to be changed in HOPE version MDC 3.0. As mentioned, a working paper detailing the changes will be forthcoming.

Since the current nominal venting subroutines are designed for use with only one vehicle, the correction vent logic has the same limitation. The correction vents must apply to the nominal vent timeline of vehicle number one.

6.0 CONCLUSIONS AND RECOMMENDATIONS

HOPE/VENT is a working modification to HOPE/MDC 2.0 which can solve or consider vent forces. The mathematical logic of HOPE/VENT has been verified and determined to function correctly. There exists only one reservation concerning the validity of the program and that is the integration of the vent force variational equations. It is the recommendation of this author that the cumbersome smoothing schemes in both the state and variational equations be replaced by an integrator which stops at discontinuities and restarts. Such an integrator already exists and has been partially tested by the author, but further verification would be necessary before it could become a part of a baseline HOPE version.

Additional studies are planned, however, to fully test the performance of the HOPE/VENT program in its present configuration. The limitations and full capabilities of solving or considering vent forces will be explored in depth.

7.0 REFERENCES

1. Rich, T. M., "HOPE Update: Version MDC 2.0," MDTSCO TM 1.4-MPB-1335, 8 September 1978.

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3. LaCarna, R. J., "Onorbit High Level and Multiple Venting Analysis and Estimation for the Shuttle Orbiter," MDTSCO Working Paper E914-8J-039, 16 October 1978.

4. Zyla, L. V., "Proposed Method to Include Venting Forces as Solve For Parameters in HOPE," MDTSCO Working Paper E914-8N-01, 5 December 1977.

APPENDIX A

MATHEMATICAL BACKGROUND

A description of the mathematical principles underlying solve/consider parameters is presented.

First, the notation that will be used is defined. Let $\vec{x} = \begin{pmatrix} x_1 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{pmatrix}$ represent a vector of solve for parameters and let $\vec{z} = \begin{pmatrix} z_1 \\ \cdot \\ \cdot \\ \cdot \\ z_n \end{pmatrix}$ be a vector of consider parameters. The solve for parameters, $\vec{x}$, may include the initial conditions for the state variables, but should not be confused with the six vector, $\begin{pmatrix} x_1 \\ \cdot \\ \cdot \\ \cdot \\ x_6 \end{pmatrix}$, which usually depicts the state variables. Observations will be denoted as

$$y_i = F_i\ (\vec{x}, \vec{z}) + \eta_i,$$

where the solve for parameters are indicated explicitly. In reality, however, the observations depend on the position and velocity of the vehicle at some time and the position and velocity may, themselves, be functions of the solve/consider variables. The term, η_i, is a noise term. The observation vector will be denoted as

$$y = \begin{pmatrix} y_1 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{pmatrix} = \begin{pmatrix} F_1\ (x, z) \\ \cdot \\ \cdot \\ \cdot \\ F_n\ (x, z) \end{pmatrix} + \begin{pmatrix} \eta_1 \\ \cdot \\ \cdot \\ \cdot \\ \eta_n \end{pmatrix} = F\ (x, z) + \eta\ ,$$

where arrows used to denote vectors have been dropped for convenience and it is understood that components of a vector have indices. Continuing with this representation, an actual observation will be denoted as

$$y^* = F\ (x, z) + \eta^*.$$

Let x_0, z_0 denote initial guesses for the solve/consider parameters. Define $\Sigma = E\left[(x_0 - x)(x_0 - x)^T\right]$.

It can easily be shown that if y^* is an actual observation and $\tilde{x}_0$ is an estimate for x, then the sequence of iterative values which minimizes the weighted squares of residuals is

$$\hat{x}_{i+1} = \hat{x}_i + \left(\Sigma^{-1} + A_i^T W A_i\right)^{-1} \left(A_i^T W (y^* - F(\hat{x}_i, z_0)) + \Sigma^{-1}(\tilde{x}_0 - \hat{x}_i)\right), \tag{A.1}$$

where

$$A_i = \frac{\partial F}{\partial x}(\hat{x}_i, z_0) = \left.\begin{pmatrix} \frac{\partial F_1}{\partial x_1} & \cdots & \frac{\partial F_1}{\partial x_n} \\ \vdots & & \vdots \\ \frac{\partial F_n}{\partial x_1} & \cdots & \frac{\partial F_n}{\partial x_n} \end{pmatrix}\right|_{(\hat{x}_i,\, z_0)}$$

Let x^* denote the solution to the minimization problem. Then x^* satisfies the equation

$$A_*^T W \left(y^* - F(x^*, z_0)\right) + \Sigma^{-1} (\tilde{x}_0 - x^*) = 0. \tag{A.2}$$

Suppose that z_0 is perturbed slightly to the new value, $z_0 + \Delta z$. How will the optimal solution, x^*, change? If Δz is sufficiently small, it can be shown that

$$\Delta x^* = \left(\Sigma^{-1} + A_*^T W A^*\right)^{-1} \left(A_*^T W \Delta y + \Sigma^{-1} (\tilde{x}_0 - x^*)\right), \tag{A.3}$$

where

$$\Delta y_* = y^* - F(x^*, z_0 + \Delta z)$$

and Δx^* is the perturbation to the optimal solution, x^*. Now

$$F(x^*, z_0 + \Delta z) \approx F(x^*, z_0) + \frac{\partial F}{\partial z}(x^*, z_0) \tag{A.4}$$

so that

$$\Delta x^* = (\Sigma^{-1} + A_*^T W A_*)^{-1} \left(A_*^T W (y^* - F(x^*, z_0)) - A_*^T W \frac{\partial F}{\partial z}(x^*, z_0)\, \Delta z \right.$$

$$\left. + \Sigma^{-1}(x_0 - x^*)\right) = -\psi_* A_*^T W B_* \Delta z \ , \tag{A.5}$$

where

$$\psi_* = (A_*^T W A^*)^{-1}$$

and

$$B_* = \frac{\partial F}{\partial z}(x^*, z_0) \ .$$

Equation (A.2) was used to simplify equation (A.5) in the next to last equality. In terms of partial derivatives, Equation (A.5) can be rewritten as

$$\frac{\partial x^*}{\partial z} = -\psi_* A_*^T W B_* \ . \tag{A.6}$$

Equation (A.6) is a sensitivity equation, telling which perturbation of a consider parameter would change the optimal solution the most.

A more meaningful estimate of uncertainties in the solve for parameters due to uncertainties in the consider parameters is provided by the covariance matrix.

Writing, once again, the iterative scheme for the optimal solution:

$$\hat{x}_{i+1} = \hat{x}_i + (\Sigma^{-1} + A_i^T W A_i)^{-1} (A_i^T W (y^* - F(\hat{x}_i, z_0)) + \Sigma^{-1} (\tilde{x}_0 - \hat{x}_i)) \quad . \tag{A.7}$$

Let x and z be the true values of the variables being estimated. Define

$$\varepsilon_{i+1} = \hat{x}_{i+1} - x \quad .$$

Now

$$\Delta y_i = y^* - F(\hat{x}_i, z_0) = \eta + F(x, z) - F(\hat{x}_i, z_0) \approx \eta - A_i \varepsilon_i + B_i \Delta z, \text{ where } \Delta z = z - z_0 \ .$$

Subtracting x from both sides of Equation (A.7) gives

$$\varepsilon_{i+1} = \varepsilon_i + \psi_i (-A_i^T W A_i \varepsilon_i + A_i^T W B_i \Delta z + A_i^T W \eta + \Sigma^{-1}(\tilde{x}_0 - \hat{x}_i)),$$

where (A.8)

$$\psi_i = (A_i^T W A_i + \Sigma^{-1})^{-1} \ .$$

Then

$$\begin{aligned} \varepsilon_{i+1} &= \psi_i (-A_i^T W A_i \varepsilon_i + A_i^T W B_i \Delta z + A_i^T W \eta \\ &\quad + \Sigma^{-1} (\tilde{x}_0 - \hat{x}_i) + A_i^T W A_i \varepsilon_i + \Sigma^{-1} \varepsilon_i \\ &= \psi_i (A_i^T W B_i \Delta z + A_i^T W \eta + \Sigma^{-1} (\tilde{x}_0 - x)) \end{aligned} \tag{A.9}$$

$$E(\varepsilon_{i+1}) = \psi_i (A_i^T W B_i E(\Delta z) + A_i^T W E(\eta) + \Sigma^{-1} E(\tilde{x}_0 - x))$$

Assuming that

a) $E(\Delta z) = 0$,

b) $E(\eta) = 0$,

c) $E(\tilde{x}_0 - x) = 0$,

then

$E(\varepsilon_{i+1}) = 0$, and we have an unbiased estimator of x.

Forming the outer product* of Equation (A.9) with itself and taking the expectation of both sides gives

$$E\left(\epsilon_{i+1}\,\epsilon_{i+1}^T\right) = \psi_i\left(A_i^T W B_i \Sigma_{\Delta z} B_i^T W A_i + A_i^T W A_i + \Sigma^{-1} + A_i^T W B_i \Sigma_{\Delta z,\Delta x_0} \Sigma^{-1} + \Sigma^{-1} \Sigma_{\Delta x_0,\Delta z} B_i^T W A_i\right) \psi_i \quad , \tag{A.10}$$

where

$$\Sigma_{\Delta x_0,\Delta z}^T = \Sigma_{\Delta z,\Delta x_0} = E\left((z - z_0)\,(\tilde{x}_0 - x)^T\right)$$

$$\Sigma_{\Delta z} = E\left((z - z_0)\,(z - z_0)^T\right) \quad .$$

Recognizing that

$$\psi_i = (A_i^T W A_i + \Sigma^{-1})^{-1},$$

we can rewrite Equation (A.10) evaluated at the converged solution, x^*, as

$$C_0 = \psi_* + \psi_*\left(A_*^T W B_* \Sigma_{\Delta z} B_*^T W A_* + A_*^T W B_* \Sigma_{\Delta z,\Delta xo} \Sigma^{-1} + \Sigma^{-1}\Sigma_{\Delta xo,\Delta z} B_*^T W A_*\right)\psi_* . \tag{A.11}$$

Here we have made use of the definition, $C_0 = E\left(\epsilon_{i+1}\,\epsilon_{i+1}^T\right)$.

We can also obtain the cross covariance matrix, $E\left(\epsilon_{i+1}\,(z - z_0)^T\right)$. If we multiply equation (A.9) by $z - z_0$ and take the expectation of both sides, we obtain

$$CR_0 = E\left(\epsilon_{i+1}\,(z - z_0)^T\right) = \psi_*\left(A_*^T W B_* \Sigma_{\Delta z} + \Sigma^{-1} \Sigma_{\Delta x_0,\Delta z}\right) \tag{A.12}$$

* The outer product of a column vector, x, is xx^T.

Suppose we are solving for the state at time, t_o. Then Equations (A.11) and (A.12) contain submatrices which contain the covariance of the state and the cross covariance of the state with all other solve/consider parameters.

In order to derive the equations for the propagation of the state covariance, we must depart from previous notation. Let $x(t) = (x_1(t), x_2(t), \ldots, x_6(t))$ denote the state and let $p = (p_1, \ldots, p_m)$ denote the set of all solve and consider parameters minus the state variables. Let the state propagation equation be written in simplified form as

$$x(t) = f\,(x\,(t_o),\, p,\, t) \tag{A.13}$$

If $\hat{x}\,(t_o)$, $\hat{p}$ are our best estimates of the true values, $x(t_o)$, p, then

$$\hat{x}\,(t) = f\,(\hat{x}\,(t_o),\, \hat{p},\, t)\ , \tag{A.14}$$

and

$$f\,(x\,(t_o),\, p,\, t) = f\,(\hat{x}(t_o),\, \hat{p},\, t) + \frac{\partial x(t)}{\partial x(t_o)}\,(x\,(t_o) - \hat{x}\,(t_o))$$
$$+ \frac{\partial x(t)}{\partial p}\,(p - \hat{p})\ .$$

We can rewrite equation (A.15) as

$$x(t) - \hat{x}(t) = \frac{\partial x(t)}{\partial x(t_o)}\,(x(t_o) - \hat{x}(t_o)) + \frac{\partial x(t)}{\partial p}\,(p - \hat{p})\ . \tag{A.16}$$

Denote $\Lambda_{\Delta x}(t) = E\,[(x(t) - \hat{x}(t))\,(x(t) - \hat{x}(t))^T]$, (A.17)

$$\Lambda_{\Delta x, \Delta p}\,(t) = E\,[(x(t) - \hat{x}(t))\,(p - \hat{p})^T], \tag{A.18}$$

and

$$\Lambda_{\Delta x, \Delta p} = E\,[(p - \hat{p})\,(p - \hat{p})^T]\ . \tag{A.19}$$

Taking the outer product of Equation (A.16) with itself we obtain

$$\Lambda_{\Delta x}(t) \quad \frac{\partial x(t)}{\partial x(t_o)} \Lambda_{\Delta x}(t_o) \quad \frac{\partial x(t)^T}{\partial x(t_o)} + \frac{\partial x(t)}{\partial x(t_o)} \Lambda_{\Delta x, \Delta p}(t_o) \quad \cdot$$

$$\frac{\partial x(t)^T}{\partial p} + \frac{\partial x(t)}{\partial p} \Lambda_{\Delta x, \Delta p}{}^T (t_o) \frac{\partial x(t)^T}{\partial x(t_o)} + \frac{\partial x(t)}{\partial p} \Lambda_{\Delta p, \Delta p} \frac{\partial x(t)^T}{\partial p} \tag{A.20}$$

The cross covariance becomes

$$\Lambda_{\Delta x, \Delta p}(t) = \frac{\partial x(t)}{\partial x(t_o)} \Lambda_{\Delta x, \Delta p}(t_o) + \frac{\partial x(t)}{\partial p} \Lambda_{\Delta p, \Delta p} \quad . \tag{A.21}$$

This completes the mathematical background for solve or consider parameters.

APPENDIX B

PARTIAL SUBROUTINE LISTINGS

The following listings of modified subroutines list only the general area of code affected and are not complete representations of the altered subroutines. For a complete listing of the modified code as well as the original code (unmodified HOPE/MDC 2.0), please contact the author.

Table B-1 - Partial Listing Subroutine ASSIGN

```
      K(12) = MALGN4 - 1
      K(13) = MALGN4
      K(14) = MATWAI - 1
      K(17) = MSTARI
      K(18) = MGBSI - 1
      K(19) = MLANDI
      K(20) = MGBBI  - 1
      K(21) = MGBBI
      K(22) = MOBBI  - 1
      K(23) = MOBBI
      K(24) = MSTARI - 1
      K(25) = MGBSI
      K(26) = MOBSI  - 1
      K(27) = MOBSI
      K(28) = MDELPT - 1
      K(29) = MDELPT
      K(30) = MMPAVC - 1
      K(33) = MATWAI
      K(34) = K(33) + NSOLVE * ( NSOLVE + 1 ) - 1
      K(31) = MMPAVC
      K(32) = MAVECI - 1
C
      CALL RANLAS ( KDRUM2 , NDRUM(48) )
      WRITE ( KDRUM2 )  ( IPOINT(I) , I = 1 , LPOINT ) ,
     1                  ( K(I) , I = 1 , LK )
      CALL ASSCKM ( 2 , 28 )
  440 DO 450 I = 17 , 60
  450 IPOINT(I) = 0
      DO 460 I = 1 , LK
  460 K(I) = 0
C
C ASSIGN FIT-APPLY-ITSUM VARIABLE STORAGE
C
  470 MAPPLY = MSTARI
      MATAI1 = MAPPLY + NSOLVE + NVC(1,1) + NVC(1,2)
      NCNSTR = NCNSTS + NVC(2,1) + NVC(2,2)
      MOLDQ  = MATAI1 + 2 * ( NATWAI + NSOLVE )
      MDQ    = MOLDQ  + 2 * ( NSOLVE + NCNSTS )
      MLABLS = MDQ    + 2 * NSOLVE
      MSCALS = MLABLS + 2 * ( NSOLVE + NCNSTS )
      MBNDS  = MSCALS + 2 * ( NSOLVE + NCNSTS )
      MLPB3  = MBNDS  + 2*NSOLVE
      MIGB3 =  MLPB3 + 16 *   NLP(1)
      MLPB4 = MIGB3 + 50*NIG(1)
      MIGB4 =  MLPB4 + 16 *   NLP(2)
      MCWEJ3=MIGB4+50*NIG(2)
      MCWEC3 = MCWEJ3                                               *NEW
      ITEMP = NJCWD(1) + NCSCWD(1)                                  **-1
      IF(ITEMP .NE. 0) MCWEC3 = MCWEC3 + NJCWD (1) + 3
      MJE3   = MCWEC3 + NCSCWD(1)
      ITEMP= MAXO(NJ(1),1 )
      IF ( NJ(1) + NCS(1) .EQ. 0 ) ITEMP = 0
      MCSE3 = MJE3 + ITEMP*2
      MCWMJ3=MCSE3+NCS(1)*2
      MCWMC3 = MCWMJ3                                               *NEW
      ITEMP = NJCWD(2) + NCSCWD(2)                                  **-1
      IF(ITEMP .NE. 0) MCWMC3 = MCWMC3 + NJCWD(2) + 3
      MJM3   = MCWMC3 + NCSCWD(2)

      ITEMP= MAXO(NJ(2),1 )
```

Table B-1 - Partial Listing Subroutine ASSIGN (Continued)

```
00561         ITEMP= MAX0(NJ(2),1 )
00562         IF ( NJ(2) + NCS(2) .EQ. 0 ) ITEMP = 0
00564         MCSM3 = MJM3 + ITEMP*2
00565         MMCON3=MCSM3+NCS(2)*2                                        *NEW
00566         MMCCW3 = MMCON3 + 2 * NPARS * NMCON                         ***1
00567         MENDFA = MAX0(MCSE3 + 2*NCS(1), MCSM3 + 2*NCS(2),
00567        1   MMCCW3,MIGB4 + 50*NIG(2)) - 1
00570         IF (MENDFA-LVSTR) 500,500,480
00573     480 IFATAL = IFATAL + 1
00574         CALL FLIP(1,IFLP)
00575         WRITE (KOUT,2200) ILINK(3), MENDFA, LVSTR
00602         GO TO 540
00602   C
00602   C  COMPUTE READ INDICES FOR FIT-APPLY-ITSUM
00602   C
00603     500 K( 1) = MOLDQ
00604         K( 2) = MLPR3 - 1
00605         K( 3) = MSFNID
00606         K( 4) = MTRI - 1
00607         K( 5) = MLPR3
00610         K( 6) = MIGR3  - 1
00611         K( 7) = MIGR3
00612         K( 8) = MLPR4  - 1
00613         K( 9) = MLPR4
00614         K(10) = MIGR4  - 1
00615         K(11) = MIGR4
00616         K(12) = MIGB4 + 50*NIG(2) - 1
00617         K(13) = MCSEJ3
00620         K(14) = MCSE3  + 2*NCS(1) - 1
00621         K(15) = MCWMJ3
00622         K(16) = MCSM3  + 2*NCS(2) - 1
00623         K(17) = MMCON3
00624         K(18) = MMCCW3 - 1
00625         K(19) = MAPPLY
00626         K(20) = MATAI1 - 1
00627         K(21) = MAPPIQ
00630         K(22) = MCNAL3 - 1
00631         K(23) = MALGN3
00632         K(24) = MCNAL4-1
00633         K(25) = MALGN4
00634         K(26) = MATWA1 - 1
00635         K(27) = MLAND1
00636         K(28) = MGRB1 - 1
00637         K(29) = MGRB1
00640         K(30) = MORB1 - 1
00641         K(31) = MORB1
00642         K(32) = MSTAR1 - 1
00643         K(33) = MTR1
00644         K(34) = MAPHIQ - 1
00644   C
00645         CALL RANLAS ( KDRUM2 , NDRUM(49) )
00646         WRITE ( KDRUM2 )  ( IPOINT(I) , I = 1 , LPOINT ) ,
00646        1                  (     K(I) , I = 1 , LK     )
00660         CALL ASSCKM ( 3 , 40 )
00661     540 DO 550 I = 1 , LPOINT
00664     550 IPOINT(I) = 0
00666         DO 560 I = 1 , LK
00671     560 K(I) = 0


00673         GO TO 700
00673   C  ASSIGN VARIABLE STORAGE FOR DUMMY DATA
```

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Table B-1 - Partial Listing Subroutine ASSIGN (Continued)

```
      MSCCV4 = MLBCV4 + 2*NPR
      MENDCR = MSCCV4 + 2*NPR
      IF (MENDCR-LVSTR) 976,976,975
  975 IFATAL = IFATAL + 1
      CALL FLIP(1,IFLP)
      WRITE (KOUT,2000) ILINK(8), MENDCR, LVSTR
      GO TO 981
  976 K( 1) = MAPLY1
      K( 2) = MATWA4 - 1
      K( 3) = MATWA4
      K( 4) = MALGN7 - 1
      K( 5) = MALGN7
      K( 6) = MALGN8 - 1
      K( 7) = MALGN8
      K( 8) = MLBCV4 - 1
      K( 9) = MLBCV4
      K(10) = MENDCR - 1
      CALL RANLAS(KDRUM2,NDRUM(59))
      WRITE (KDRUM2) (IPOINT(I),I=1,LPOINT),
     *               (       K(I),I=1,LK)
      CALL ASSCKM(8,I0)
  981 DO 982 I = 1 , LPOINT
  982 IPOINT(I) = 0
      DO 984 I=1,LK
  984 K(I) = 0
C
C  ASSIGN VEHICLE ONE TRAJECTORY VARIABLE STORAGE
  986 NYMAX2 = 2 * NYMAX(1)
      MYTRG  = 1
C
      MDIF1 = MYTRG + 10 * NYTRG
C
      MY1    = MDIF1   + 26 * NYMAX(1)
      MYP1   = MY1     + NYMAX2
      MYPP1  = MYP1    + NYMAX2
C
      MTTRG1 = MYPP1   + NYMAX2
C
      MAUX1  = MTTRG1 + 4 * NTTRG(1)
C
      MCNAL1 = MAUX1  + 2 * NAUX1
      MALGN1 = MCNAL1 + 12 * NAL1
      MCNLP1 = MALGN1 + 20 * NAL1
      MLNY1  = MCNLP1 + 8 * NLP(1)
      MCNIG1 = MLNY1  + NLP(1)
      MINY1  = MCNIG1 + 21 * NIG(1)
      MLPR1  = MINY1  + NIG(1)
      MIGR1 =  MLPR1  + 16 *   NLP(1)
C
      MCWEJ1 = MIGR1 + 53*NIG(1)
      MCWEC1 = MCWEJ1
      ITEMP = NJCWD(1) + NCSCWD(1)
      IF (ITEMP .NE. 0) MCWEC1 = MCWEC1 + NJCWD(1) + 3
      MJE1   = MCWEC1 + NCSCWD(1)
      ITEMP= MAX0(NJ(1),1 )
      IF ( NJ(1) + NCS(1) .EQ. 0 ) ITEMP = 0
      MCSE1 = MJE1 + ITEMP*2
      MCWMJ1=MCSE1+2*NCS(1)                                        *NEW

      MCWMC1 = MCWMJ1                                              **-1
      ITEMP = NJCWD(2) + NCSCWD(2)
      [illegible] MCWMC1 = MCWMC1 + NJCWD(2) + 3
```

Table B-1 - Partial Listing Subroutine ASSIGN (Continued)

```
      MCWMCI = MCWMJI
      ITEMP = NJCWD(2) + NCSCWD(2)                                       **-1
      IF (ITEMP .NE. 0) MCWMCI = MCWMCI + NJCWD(2) + 3
      MJMI   = MCWMCI + NCSCWD(2)
      ITEMP= MAX0(NJ(2),1 )
      IF ( NJ(2) + NCS(2) .EQ. 0 ) ITEMP = 0
      MCSMI = MJMI + ITEMP*2
      MMCONI = MCSMI  + 2 * NCS(2)
      MMCCWI=MMCONI+(2*NPARS)*NMCON+7*NMCON                             *NEW
      MVTAB=MMCCWI+NMCODE                                               *NEW
      MBTAB = MVTAB+ 10*NVTAB                                           **-2
      METAB = MBTAB + 24*NBTAB
      MWTAB = METAB + 8*NETAB
      MMCAGA= MWTAB + 6*NWTAB
      MLAND3 = MMCAGA + 644 * NUMWM
      MSUNP = MLAND3 + 8 * NLAND * (MOD(LNDTR(1),4)/3)
      MSEVI = MSUNP + 24 * NSZI
      MENDTI = LVSTR
      IF (MSEVI - LVSTR)  990,990,980
  980 IFATAL = IFATAL + 1
      CALL FLIP(1,IFLM)
      WRITE (KOUT,2602)  ILINK(8), MENDTI,  LVSTR
      GO TO 999
  990 NEVTMX(1) = (LVSTR - MSEVI + 1)/4
      IF (NEVTMX(1).LT.0) NEVTMX(1) = 0
C
C  COMPUTE READ INDICES FOR TRAJRD
C
      K( 1) = MYTRG
      K( 2) = MDIFI   - 1
      K( 3) = MCNALI
      K( 4) = MALGNI  - 1
      K( 5) = MALGNI
      K( 6) = MCNLPI  - 1
      K( 7) = MCNLPI
      K( 8) = MCNIGI  - 1
      K( 9) = MCNYGI
      K(10) = MLPRI   - 1
      K(11) = MLPRI
      K(12) = MIGRI   - 1
      K(13) = MIGRI
      K(14) = MCWEJI  - 1
C
      K(15) = MCWEJI
      K(16) = MCSEI   + 2 * NCS(1) - 1
      K(17) = MCWMJI
      K(18) = MCSMI  + 2 * NCS(2) - 1
      K(19) = MMCONI
      K(20) = MMCONI  + (2*NPARS)*NMCON - 1
      K(21) = MMCCWI
      K(22) = MMCCWI  + NMCODE - 1
      K(23)=MVTAB
      K(24)=MBTAB -1
      K(25)=MBTAB
      K(26)=METAB  -1
      K(27)=METAB
      K(28)=MWTAB  -1
      K(29)=MWTAB

      K(30)=MMCAGA -1
      K(31)=MLAND3
      K(32)=MSUNP -1
      [illegible]
```


4

Table B-2 - Partial Listing Subroutine DAUX

```
C0100     CD          WHEN THE DAUX, ENTRY IS CALLED, THE ADDRESSES OF Y, YP,
C0100     CD          AND YPP IN VSTR ARE ESTABLISHED, AND THE POINTERS FOR THE
C0100     CD          POTENTIAL, MASS RATIOS, AND WASOONS TO YPP ARE SET UP.
C0100     CD          ON EVERY SUBSEQUENT CALL UNTIL PHASE CHANGE, THE ENTRY
C0100     CD          POINT DAUX IS CALLED.  THE ACCELERATIONS ON THE SPACECRAFT
C0100     CD          THAT ARE MODELED ARE
C0100     CD                (1) PERTURBING BODIES OTHER THAN CENTRAL BODY (SUBR BODY)
C0100     CD                (2) IGS BURNS (SUBR IGSBRN)
C0100     CD                (3) LOP BURNS (SUBR LOPBRN)
C0100     CD                (4) ATMOSPHERIC RESISTANCE (SUBR DRAG)
C0100     CD                (5) POINT MASS EFFECT OF CENTRAL BODY (COMPUTED IN DAUX)
C0100     CD                (6) POTENTIAL EFFECTS DUE TO A NON-HOMOGENEUUS,
C0100     CD                    NON-SPHERICAL CENTRAL BODY (SUAR GPOT)
C0100     CD          BEFORE SUBROUTINE GPOT IS CALLED, DAUX ROTATES THE MEAN-OF-
C0100     CD          1952 SPACECRAFT POSITION TO BODY FIXED.  IF THE EARTH IS
C0100     CD          THE CENTRAL BODY, THE BODY FIXED COORDINATES ARE OBTAINED
C0100     CD          USING THE TTOMT MATRIX TO GET FROM MEAN-OF-50 TO TRUE OF
C0100     CD          MIDNIGHT DAY OF EPOCH, VEHICLE 1.  THEN THE GREENWICH HOUR
C0100     CD          ANGLE (CALPHG), THE ROTATION RATE OF THE EARTH (CWE), AND
C0100     CD          THE TIME IN MINUTES PAST MIDNIGHT DAY OF EPOCH (TPM) ARE
C0100     CD          USED TO CONVERT TO BODY FIXED.  IF THE MOON IS THE CENTRAL
C0100     CD          BODY, THE SPACECRAFT POSITION IS ROTATED FROM MEAN-OF-1950
C0100     CD          TO SELENOGRAPHIC.
C0100     CD          ADDED TO THE PUMAT IN DAUX ARE THE VARIATIONS DUE TO THE
C0100     CD          CENTRAL BODY, J2 OF THE EARTH, AND THE CDAD2M TERM.
C0100     CD
C0100     CD. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C0101           SUBROUTINE DAUX (Y,YP,SUNARY,ISZ,YPP,VTAB,RTAB,ETAB,WTAB)
C0103           IMPLICIT DOUBLE PRECISION (A-H,O-Z), INTEGER (I-N)
C0103     C...BEGIN STANDARD COMMON FOR SUBROUTINE DAUX              10/04/72
C0104           DOUBLE PRECISION  BASE   ,BFY    ,CALPHG,CDAD2M,CETUT ,CGMK   ,CMU
C0105           DOUBLE PRECISION  CWE    ,DAY
C0106           DIMENSION       DFX   (    3),CDAD2M(    2),CGMR  (   12)
C0107           DIMENSION       IAPT  (   4,  25)
C0110           DOUBLE PRECISION  PADM   ,PVMAT
C0111           INTEGER              PER3OD,RFLWRD
C0112           DIMENSION       NCENTR(    2),NCS   (    2),NJ    (    2),PADM  (    2)
C0112          D,PERBOD(   11)
C0113           DIMENSION       PVMAT (   3,    6)
C0114           DOUBLE PRECISION  SRANGE,TBLOCK,TBPERT,TBURN ,TDRAG ,TPOT   ,TTOM
C0115           DOUBLE PRECISION  TTOMT
C0116           INTEGER              STOCKD,VECJ   ,YES
C0117           DIMENSION       TBLOCK(    4),TBPERT(    3),TBURN (    3),TDRAG (    3)
C0117          D,TPOT  (    3),VECJ  (    2)
C0117          D , TLLTH(3)
C0120           DOUBLE PRECISION  RNP(3,3)
C0121           DOUBLE PRECISION TCCFF(3)
C0122           DOUBLE PRECISION Z(3,10),TIMEZ(6)
C0123           DIMENSION ITIME(6)
C0124           DOUBLE PRECISION TABOUT( 9, 12)
C0125           DOUBLE PRECISION RBECI(3,3)
C0126           DIMENSION       TTOM  (   3,    3),TTOMT (   3,    3)
C0127           DOUBLE PRECISION CONST, CONFIX, SCRCOM, EBUF
C0130           COMMON/VENX/VOTAB(5,59)                                          .NEW
C0131           COMMON/        /CONST (250), KONST (750), CONFIX (400)
C0131          C,                KONFIX ( 500), LENGTH ( 100), IPOINT (   60)
C0131          C,                KPOINT (   60), SCRCOM ( 200), EBUF (1000)
C0132           DOUBLE PRECISION TRAJD

C0133           COMMON / TRAJEC / TRAJ ( 200), ITRAJ ( 40)
```

```
00140                 1 ,              (TTOMT (1)   ,  CONFIX ( 254) )
00140                 1 ,              (VECJ  (1)   ,  LENGTH (  50) )
00140                 1 ,              (YES         ,  KONST  ( 194) )
00140          C...END STANDARD COMMON FOR SUBROUTINE DAUX             10/04/72
00141                DOUBLE PRECISION SUNARY
00142                DIMENSION SUNARY(12,ISZ)
00143                DOUBLE PRECISION  MASMAT(3,3), ROMAT(3,3), ROTMAT(3,3)
00144                DOUBLE PRECISION Y(1), YP(1), YPP(1)
00145                DOUBLE PRECISION  TRAD
00146                DOUBLE PRECISION TOLD
00147                DOUBLE PRECISION UVWMAT(6,6),TLLUVW(3)
00150                DOUBLE PRECISION WTAB(3,1),VTAB(5,1),BTAB(12,1),ETAB(4,1)
00151                DOUBLE PRECISION  CENVEH(3)
00152                DIMENSION TRAD(3)                                            SW021670
00153                DIMENSION B(3),RY(3)
00154                DOUBLE PRECISION                 EFMAT(3,3),       TEMP(3)
00155                INTEGER                          OPT(2)
00156                EQUIVALENCE (SRANGE,TR)
00157                DATA EFMAT(1,3), EFMAT(2,3),EFMAT(3,1),EFMAT(3,2) /4*0.D0/,
00157               1      EFMAT(3,3)/1.D0/
00165                DATA OPT/12,124/
00167                IF(NVTAB.EQ.0) GO TO 556                                         .NEW
00171                 DO 555 JJ=1,NVTAB                                               .NEW
00174                DO 555 II=1,5                                                    .NEW
00177                VOTAB(II,JJ)=VTAB(II,JJ)                                         .NEW
00200          555    CONTINUE                                                        .NEW
00203          556   CONTINUE                                                         .NEW
00204                NCOL = (NY-3) / 3
00205                IALT = 1
00206                IPRINT = 0
00207                IOPRT = 0
00210                I1 = (KVEH-1) * 18 + 2
00211                J1 = 0
00212                IF (FLD(I1,2,STOCWD) .NE. 0)  J1 = 1
00214                KFUST = 3*J1 + 27
00215                I1 = IABS((KVEH-1)*2)
00216                J1 = 0
00217                IPADM = FLD(I1,2,RFLWRD)
00220                IF (IPADM .NE. 0)  J1 = 1
00222                IPOTE = KFUST + 3*J1
00223                IPOTM = IPOTE + 3 * VECJ(1)
00224                IBODY = IPOTM + 3 * VECJ(2)
00225                NFUST = IBODY + 3 * (NMRSOL + NMRCON)
00226                IEPSTR = NFUST + 3*(NSOLKP + NCNDKP)
00227                IETOT = NSOLEP + NCNSEP
00230                IMASCN = IEPSTR + 3*IETOT
00231                ICC=1                                                            .NEW
00232                WRITE(6,51) IMASCN                                               .NEW
00235           51   FORMAT(10H IMASCN = I3)                                          .NEW
00236                WRITE(6,52) NMCON                                                .NEW
00241           52   FORMAT(9H NMCON = I3)                                            .NEW
00242                WRITE(6,55) NY                                                   .NEW
00245           55   FORMAT( 6H NY = I3)                                              .NEW
00246                K1 = 6 * (KVEH - 1) + 1
00247                LOPIGS = 3 * (IAPT(4,K1) + IAPT(4,13) + 1) + 1
00250                TOLD = TBLOCK(1) + 1000.D0
00251                TINIT = TBLOCK(1)
00252                CALL FLIP(NVTAB+3,IFLP)

00253                WRITE(KOUT,602) (( VTAB(I,J),I=1,5),J=1,NVTAB )
00254          602   FORMAT (1H1,' VTAB ARRAY BY COLUMNS'//(4X,5G25.18))
```


6

Table B-2 - Partial Listing Subroutine DAUX (Continued)

```
C00460            MASMAT(I,J) = 0.00
C00461      2001  PVMAT(I,J) = PVMAT(I,J) + ROMAT(I,J)
C00464      2005  ISW = ISW + 1
C00465      2100  CONTINUE                                                          **-1
C00465      C
C00465      C ROTATE BACK TO MEAN OF 1950
C00465      C
C00466            IF (NCENTR(KVEH) .NE. 11) GO TO 275
C00470            DO 273 I=1,3
C00473       273  TEMP(I) = TPOT(I)
C00475            GO TO 288
C00476       275  EFMAT(1,2) = EFMAT(2,1)
C00477            EFMAT(2,1) = -EFMAT(2,1)
C00500            CALL MMPY(3,3,1, EFMAT,3,TPOT,1,TEMP,1 )
C00501       285  CALL MMPY(3,3,1,TTOM,3,TEMP,1,TPOT,1)
C00502            IF (NGPOT .EQ. 0  .OR.   IFLAG .LT. 0) GO TO 290
C00504            DO 286 I=1,NGPOT
C00507            CALL MMPY(3,3,1,EFMAT,3,YPP(NJCS),1,TEMP,1)
C00510            CALL MMPY(3,3,1,TTOM,3,TEMP,1,YPP(NJCS),1)
C00511       286  NJCS = NJCS +3
C00513            GO TO 290
C00514       288  CALL ROTAT(-OPT(IROTFL),TIME,TEMP,TPOT,CETUT)
C00515            IF ( NGPOT .EQ. 0  .OR.  IFLAG .LT. 0 ) GO TO 2090
C00517            DO 289 I=1,NGPOT
C00522            CALL ROTAT(-OPT(IROTFL),TIME, YPP(NJCS), YPP(NJCS),CETUT)
C00523       289  NJCS = NJCS + 3
C00525      2090   CONTINUE                                                         *NEW
C00526      2095   CONTINUE                                                         *NEW
C00527       290  CONTINUE                                                          ***6
C00527      C
C00527      C              CALCULATE ACCELERATIONS DUE TO LOW LEVEL THRUSTING
C00527      C              AND/OR DRAG IF REQUESTED
C00527      C
C00530            IF(KVEH.EQ.2) GO TO 291
C00532  *DIAGNOSTIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
C00532            IF(IVENT.EQ.0.AND.CDAD2H(1).EQ.0) GO TO 350
C00532      C
C00532      C              RECOMPUTE ATTITUDE COMPUTATIONS FOR IH OR BBQ MODES
C00532      C              ONLY IF TIME HAS CHANGED. ALWAYS RECOMPUTE FOR SI OR LVLH
C00532      C              LOOK UP VEHICLE MASS AND CONFIGURATION
C00532      C
C00534       292  CALL VMASS(WTAB)                                                  ***3
C00535       293  CONTINUE
C00535      C
C00535      C              COMPUTE BODY ATTITUDE TO ECI IF MATRIX REQUIRED
C00535      C
C00536            IF(IBATT.EQ.0) GO TO 291
C00540            CALL BODATT(BTAB,ETAB,Y,YP)
C00540      C
C00540      C              COMPUTE LOW LEVEL THRUST ACC. IF THRUST REQUIRED
C00540      C
C00541            IF(IVENT.EQ.0) GO TO 291
C00543            CALL SHVENT(VTAB)
C00544            IF(NMCON.EQ.0) GO TO 297                                          *NEW
C00546            IF(IBATT.EQ.0.AND.NMCON.GT.0) GO TO  299                          *NEW
C00550            CALL BODATT(BTAB,ETAB,Y,YP)                                       *NEW
C00551            CALL VMASS(WTAB)                                                  *NEW
C00552            IF(NMCON.GT.0.AND.KVEH.EQ.1) CALL MASACC(YPP(IMASCN),MASMAT)      *NEW

C00554            GO TO 297                                                         *NEW
                                                                                    *NEW
```

B-2.3

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```
          GO TO 297                                                       NEW
  299     WRITE(6,298)                                                    NEW
  298     FORMAT(56H CORRECTION VENTS REQUESTED AND NO ATTITUDE MATRIX INPUT    NEW
         ,)                                                               NEW
  297     CONTINUE                                                        NEW
C
C                 CENTRAL BODY = EARTH?  DRAG REQUESTED?
C
DIAGNOSTIC  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
  291 IF (CDAD2M(KVEH) .EQ. 0.D0 .OR. NCENTR(KVEH) .NE. 3) GO TO 350
      CALL DRAG( Y, YP, SUNARY, ISZ )
C
C SUM UP ALL PERTURBATIONS
C
  350 CONTINUE
      KBURN1 = KBURN + 1
      GO TO (390,360,370) , KBURN1
C
C  GET LOP BURN INFORMATION
C
  360 IF(IFLAG.EQ.2)  GO TO 390
      CALL LOPBRN(YPP(LOPIGS))
      GO TO 390
C
C  GET IGS BURN INFORMATION
C
  370 CONTINUE
      CALL IGSBRN(YPP(LOPIGS))
  390 CONTINUE
DIAGNOSTIC  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF (PADM(KVEH) .EQ. 0.D0 .AND. (IPADM+NSOLKP+NCNDKP) .EQ. 0)
     *    GO TO 391
      CALL SOLRAD ( ICENTR, KFUST,NFUST,Y,TRAD,YPP )
  391 CONTINUE
      DO 400 I=1,3
      TCCFF(I) = (-Y(I)/TR3)*CMU*CGMR(ICENTR)
  400 YPP(I) = (-Y(I)/TR3)*CMU*CGMR(ICENTR) + (TBPERT(I) + TPOT(I) + TDR
     1AG(I) + TBURN(I) + TRAD(I) + TLLTH(I) )
C
C
C
      IF(IOFLAG.EQ.1) GO TO 450
      GO TO 470
  450  CONTINUE                                                           NEW
      DO 451 I = 1,3                                                      ..1
      CENVEH(I) = TABOUT(I,10) - Y(I)
C
C  IF ATTITUDE MODE IS SI, TLLTH (LOW LEVEL THRUST) IS
C  ROTATED INTO A UVW FRAME BASED UPON SUN POSITION WRT
C  VEHICLE AND VEHICLE VELOCITY VECTOR AND PRINTED AS
C  TLLUVW.  IF MODE IS NOT SI, TLLUVW IS STANDARD
C  UVW COORDINATES FOR TLLTH
  451 IF( MDE.NE.4 ) CENVEH(I) = Y(I)
      CALL UVW( CENVEH , YP , UVWMAT )
      CALL MMPY(3,3,1,UVWMAT,6,TLLTH,1,TLLUVW,1)
      WRITE (KOUT,1000)
 1000 FORMAT (23H0CKMODE PRINT FROM DAUX)
      WRITE (KOUT,998) TBLOCK(1),TBLOCK(4),TOLDSV,ICALL,MDE,IBATT,IVENT

  998 FORMAT(13H TBLOCK(1) = D26.18,13H TBLOCK(4) = D26.18,10H TOLOSV =
     1D26.18/9H ICALL = I2,7H MDE = I2,9H IBATT = I2,9H IVENT = I2 )
      WRITE(KOUT,997) (TPOT(I),TBPERT(I),TDRAG(I),TBURN(I),TLLTH(I))
```

```
  998 FORMAT(13H TBLOCK(1) = D26.18,13H TBLOCK(4) = D26.18,10H TOLOSV =
     ,D26.18/9H ICALL = I2,7H MDE = I2,9H IDATT = I2,9H IVENT = I2 )
      WRITE(KOUT,997) (TPOT(I),TBPERT(I),TDRAG(I),TBURN(I),TLLTH(I),
     *               I=1,3)
  997 FORMAT(1X4HTPOT22X6HTBPERT20X5HTDRAG21X5HTBURN21X5HTLLTH /
     *        (5D26.18) )
      WRITE(KOUT,1001) ( TRAD(I),TCCFF(I),TLLUVW(I),I=1,3 )
 1001 FORMAT(1X,'TRAD',21X,'TCCFF',22X,'TLLUVW' / (3D26.18) )
C
C
      EFMAT(1,2) = -EFMAT(1,2)
      EFMAT(2,1) = -EFMAT(2,1)
      CALL MMPY ( 3,3,3,EFMAT,3,TTOMT,3,RNP,3 )
      EFMAT(1,2) = -EFMAT(1,2)
      EFMAT(2,1) = -EFMAT(2,1)
C
C
      WRITE(KOUT,1003) ((  RNP(I,J),J=1,3),I=1,3)
 1003 FORMAT(1X,'  RNP IN STANDARD FORM' / (3D26.18)    )
      WRITE(KOUT,1005) ANGLE
 1005 FORMAT(1X7HANGLE =,D26.18/)
  999 FORMAT( 7H YYPYPP/(3D30.18))
      XJD = BASE + TBLOCK(1)*DAY
      CALL JULCAL(TIMEZ,XJD)
      DO 1181 I=1,6
 1181 ITIME(I) = TIMEZ(I) + .001D0
      SEC = TIMEZ(6)
      DO 1188 J=1,3
      Z(J,2) = 3.6D3*TBPERT(J)
      Z(J,3) = 3.6D3*TBURN(J)
      Z(J,4) = 3.6D3*TCCFF(J)
      Z(J,5) = 3.6D3*TDRAG(J)
      Z(J,6) = 3.6D3*TLLTH(J)
      Z(J,7) = 3.6D3*TPOT(J)
      Z(J,8) = 3.6D3*TRAD(J)
      Z(J,9) = 6.D1 *YP(J)
      Z(J,10) = 3.6D3*YPP(J)
 1188 CONTINUE
      Z(1,1) = TIMEZ(6)
      Z(2,1) = TBLOCK(4) /6.D1
      Z(3,1) = ANGLE *57.29577951308232D0D0
      WRITE(KOUT,1191) (ITIME(J),J=1,5),SEC
      WRITE(KOUT,1192) Z
 1191 FORMAT('0*****CHECKMODE FROM DAUX AT GMT = ',5(1X,I2),1X,F6.3
     1,'**************',/)
 1192 FORMAT(' SEC = ',F6.3,9X,'STEP (HR ) = ',G25.18,9X,'GHA (DEG) = ',
     *G25.18/
     *' TBPERT (ER/HR**2) = ',3G27.18/' TBURN  (ER/HR**2) = ',3G27.18/
     *' TCCFF  (ER/HR**2) = ',3G27.18/' TDRAG  (ER/HR**2) = ',3G27.18/
     *' TLLTH  (ER/HR**2) = ',3G27.18/' TPOT   (ER/HR**2) = ',3G27.18/
     *' TRAD   (ER/HR**2) = ',3G27.18/' YP     (ER/HR)    = ',3G27.18/
     *' YPP    (ER/HR**2) = ',3G27.18/                                )
      WRITE(KOUT,1194) ((RBECI(L,M),M=1,3),L=1,3)
 1194 FORMAT('0 RBECI MATRIX IN STANDARD FORM'//(4X,3G30.18) )
      WRITE(KOUT,1193)  ( TABOUT(I,10) , TABOUT(I,11) , I=1,3 )
 1193 FORMAT(1X,'SUN',22X,'MOON' / (2D26.18) )
C
C
C
```

B-2.5

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```
      C
      C
      C
      C ADD TO THE PVMAT THE VARIATIONS DUE TO THE CENTRAL BODY, J2 OF THE
      C EARTH, AND THE CDAD2M TERM
      C
      C GET CENTRAL BODY TERM
      C
        470 II = IABS(KVEH-1) * 18
            IF (FLD(II,2,STDCWD) .EQ. 0 .OR. IFLAG .LT. 0)  GO TO 755
            TR5=TR3*TR2
            A = 3.D0 * CMU * CGMR(ICENTR) / TR5
            DO 600 I=1,3
        600 B(I)=Y(I)*A
            CALL OUTER(B,1,Y,1,PVMAT)
            A = CMU * CGMR(ICENTR) / TR3
            DO 650 I=1,3
        650 PVMAT(I,I)=PVMAT(I,I)-A
        660 IF (NCENTR(KVEH) .NE. 3) GO TO 670
      C                               TEST      FOR              J2     TERM
            IF ( IFLA .EQ. 0 ) GO TO 670
            CALL MMPY ( 3,3,3,EFMAT,3,MASMAT,3,ROTMAT,3 )
            CALL MTRN ( 3,3,EFMAT,3,MASMAT,3 )
            CALL MMPY ( 3,3,3,ROTMAT,3,MASMAT,3,ROMAT,3 )
            CALL MMPY ( 3,3,3,TTOM,3,ROMAT,3,ROTMAT,3 )
            CALL MMPY ( 3,3,3,ROTMAT,3,TTOMT,3,ROMAT,3 )
            DO 661 I = 1,3
            DO 661 J = 1,3
        661 PVMAT(I,J) = PVMAT(I,J) + ROMAT(I,J)
      C                               TEST      FOR              CDAD2M     TERM
 DIAGNOSTIC* THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
        670 IF (CDAD2M(KVEH) .EQ. 0.D0) GO TO 750
            II = (KVEH-1) * 18 + 2
            IF (FLD(II,2,STDCWD) .EQ. 0)  GO TO 750
      C
            IFLAG = IFLAG
      C
            DO 700 I=1,3
      C
      C
        700 YPP(21 + I) = TDRAG(I) / CDAD2M(KVEH)
        750 CONTINUE
            CALL MATPLY(PVMAT,Y(4),YP(4),NCOL,YPP(4))
        755 CONTINUE
            IF(IOFLAG.NE.1) GO TO 760
            WRITE(KOUT,999) (Y(I),YP(I),YPP(I),I=1,NY)
        760 IPRINT = IPRINT + 1
            IOPRT = IOPRT + 1
        900 RETURN
            END

END OF COMPILATION:        5 DIAGNOSTICS.
DAUX          SYMBOLIC            02 SEP 78  06:09:11   0  02435606  15  613  IDELETE
DAUX   CODE   RELOCATABLE         02 SEP 78  06:09:11   1  02373412  48    1  IDELETE
                                                        0  02373472  19  169
```

@ FOR,* MASACC.MASACC   01 DEC 78
UNIVAC 1100 FORTRAN V EXEC II LEVEL 25A -(EXEC8 LEVEL E1200200010A)

/0

Table B-3 - Partial Listing Subroutine MASACC

```
00100   CD          STDCWD- SOLVE/CONSID CODE WORD FOR STATE/DRAG
00100   CD          KVEH  - CURRENT VEHICLE
00100   CD       CARD
00100   CD          NONE
00100   CD       TAPE
00100   CD          NONE
00100   CD
00100   CD     OUTPUT
00100   CD       CALLING SEQUENCE
00100   CD          PART  - STARTING LOCATION FOR VECTOR OF MASCON PARTIALS
00100   CD          MASMAT- MASCON MATRIX
00100   CD       COMMON
00100   CD          TPOT  - ACCELERATIONS DUE TO GRAVITATIONAL POTEN.
00100   CD          GMMCON- TOTAL MASS OF MASCONS IN LUNAR MASSES
00100   CD       CARD
00100   CD          NONE
00100   CD       PRINT
00100   CD          NONE
00100   CD       TAPE
00100   CD          NONE
00100   CD
00100   CD    REMARKS AND RESTRICTIONS
00100   CD          NONE
00100   CD
00100   CD    SUBROUTINES REQUIRED
00100   CD          VMAG2, MATOPS, FLIP
00100   CD
00100   CD    METHOD
00100   CD          MASCONS ARE TREATED AS EITHER POINT MASSES OR AS 'WASHER
00100   CD          SHAPED' BODIES. IN EITHER CASE THE MASCONS ARE ASSUMED TO
00100   CD          BE RIGIDLY EMBEDDED IN THE MOON
00100   CD
00100   CD. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
00101         SUBROUTINE MCINIT(MASCON,MASCW,ALPHA,GAMMA,VTAB)                   *NEW
00103         COMMON/TIMRK/ HERET,THERET,TTRUI                                    *NEW
00103   C***BEGIN STANDARD COMMON FOR SUBROUTINE MASACC        10/04/72           **-1
00104         DOUBLE PRECISION  BFY    ,CMU    ,CRCB   ,GMLUNT,GMMCON,SCRAT ,TPOT
00105         INTEGER            STDCWD
00106         DIMENSION      BFY    (     3),CRCB   (   1),SCRAT ( 200),TPOT   (    3)
00107         DOUBLE PRECISION TRAJD
00110         COMMON / TRAJEC / TRAJD ( 200), ITRAJ (   40)
00111         DOUBLE PRECISION CONST, CONFIX, SCRCOM, EBUF
00112         COMMON/        /CONST (250), KONST (250), CONFIX (400)
00112   C*                    KONFIX ( 500), LENGTH ( 100), IPOINT (   60)
00112   C*                    KPOINT (  60), SCRCOM ( 200), EBUF (1000)
00113         DOUBLE PRECISION TTEST,T1,T2,S,TS                                   *NEW
00114         DOUBLE PRECISION CNT                                                *NEW
00115         DOUBLE PRECISION TTEMP(1),VTAB(5,1),RBECI(9),WEIGHT,TBLOCK(1)       *NEW
00116         DOUBLE PRECISION HERET,THERET,TTRUI,TTRUE                           *NEW
00117         EQUIVALENCE(RBECI(1),TRAJD(144))                                    *NEW
00120         EQUIVALENCE(WEIGHT,TRAJD(157))                                      *NEW
00121         EQUIVALENCE(TBLOCK(1),CONFIX(170))                                  *NEW
00122         EQUIVALENCE(NMCCON,LENGTH(69))                                      *NEW
00123         EQUIVALENCE(NMCSOL,LENGTH(79))                                      *NEW
00124         EQUIVALENCE(NVTAB,KONST(227))                                       *NEW
00125         EQUIVALENCE (BFY    (1)   ,  TRAJD   (    1) )
00125        1 ,          (CMU          ,  CONST   (   15) )
00125        1 ,          (CRCB   (1)   ,  CONST   (   28) )



00125        1 ,          (GMLUNT       ,  CONFIX  ( 252) )
             1 ,          (GMMCON       ,  CONFIX  ( 253) )
```

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```
     1 *             (GMLUNT     ,  CONFIX ( 252) )
     1 *             (GMMCON     ,  CONFIX ( 253) )
     1 *             (IFLAG      ,  ITRAJ  (   2) )
     1 *             (KVEH       ,  KONFIX (  12) )
     1 *             (NMCODE     ,  LENGTH (  64) )
     1 *             (NMCON      ,  LENGTH (  26) )
     1 *             (SCRAT  (1) ,  SCRCOM (   1) )
     1 *             (STDCWD     ,  KONFIX (   1) )
     1 *             (TPOT   (1) ,  TRAJD  (   5) )
C**.END STANDARD COMMON FOR SUBROUTINE MASACC                    10/04/72
      DOUBLE PRECISION MASMAT(3,3)
      DOUBLE PRECISION  MASCON, PART, MASS, PHI, LAM, D,
                        SPHI, CPHI, SLAM, CLAM, PMCN, TR, TR2, TR3
     *   ,GCON   ,TEMP   ,SPAR   ,RIV    ,PMAT   ,SVEC
     *,ARAD,BRAD,NMCT,POLN(41),POLNP(41),SPHE,CONSN,VAR1,VAR2,ARSUM
     * ,ATSUM,SUMTRM,ARSAV1,ATSAV1,ARSAV2,ATSAV2,UACC(3),TERM3,DGH(3,3)
     *,RT(3), RMTX(3), ALPHA, GAMMA, SL, CU, CL, SB
      LOGICAL      MASSOL,PLHTES
      DIMENSION    MASCON(1),MASCW(1),ALPHA(1),GAMMA(1)
      DIMENSION    PART   ( 3,1) ,PMCN   (    3)
     *             ,SPAR   (    3) ,RIV    (    3) ,PMAT   ( 3,3) ,SVEC   (    3)
     *             ,ISCRAT (100)
      EQUIVALENCE             (SCRAT (151),ISCRAT)  ,(SCRAT (   1),MASS   )
     *,(SCRAT (   2),PHI    ) ,(SCRAT (   3),LAM    ) ,(SCRAT (   4),D      )
     *,(SCRAT (   5),SPHI   ) ,(SCRAT (   6),CPHI   ) ,(SCRAT (   7),SLAM   )
     *,(SCRAT (   8),CLAM   ) ,(SCRAT (   9),PMCN   ) ,(SCRAT (  12),TR     )
     *,(SCRAT (  13),TR2    ) ,(SCRAT (  14),TR3    ) ,(SCRAT (  15),GCON   )
     *,(SCRAT (  16),TEMP   ) ,(SCRAT (  17),SPAR   ) ,(SCRAT (  20),RIV    )
     *,(SCRAT (  23),PMAT   ) ,(SCRAT (  32),SVEC   )
     *,(ISCRAT(   1),IVPAR  ) ,(ISCRAT(   2),ICW    ) ,(ISCRAT(   3),KODNO  )
     *,(ISCRAT(   4),KODES  ) ,(ISCRAT(   5),IMC    ) ,(ISCRAT(   6),J      )
     *,(ISCRAT(   7),IPAR   ) ,(ISCRAT(   8),MCST   ) ,(ISCRAT(   9),I      )
     *,(ISCRAT(  10),PLHTES)
      DOUBLE PRECISION TIMEOD
      EQUIVALENCE (CONFIX(170),TIMEOD)
      DATA MAXTRM /22/
      DATA NEARS / 9 /
      DATA  MASSOL / .FALSE. /
C   INITIALIZE SUBROUTINE                                               *NEW
       ICC=1                                                            *NEW
      YYY=-1.0                                                          *NEW
      IF(NMCON.GT.0.AND.NVTAB.EQ.0) QQQ=SQRT(YYY)                       *NEW
      [illegible]O 5 J=1,NMCON                                          *NEW
      DO 5  I=1,NVTAB                                                   *NEW
      [illegible]=(J-1)*9 + 6                                           *NEW
      IPYL=(J-1)*9+7                                                    *NEW
      IF(VTAB(1,I).GE.MASCON(IZYL).AND.VTAB(2,I).LE.MASCON(IPYL))GO TO 7 *NEW
      GO TO 5                                                           *NEW
    7 IDUM1=(J-1)*9+1                                                   *NEW
      IDUM2=(J-1)*9+2                                                   *NEW
      IDUM3=(J-1)*9+3                                                   *NEW
      VTAB(3,I)=VTAB(3,I)+MASCON(IDUM1)                                 *NEW
      VTAB(4,I)= VTAB(4,I)+MASCON(IDUM2)                                *NEW
      VTAB(5,I)=VTAB(5,I)+MASCON(IDUM3)                                 *NEW
    5 CONTINUE                                                          *NEW
      WRITE(6,504) (MASCW(IA),IA=1,NMCODE)                              *NEW
  504 FORMAT( 9H MASCW = O12)                                           *NEW
      NM=9*NMCON

      WRITE(6,584)(MASCON(IZZ),IZZ=1,NM)                                *NEW
  584 FORMAT(10H MASCON = 9D13.6)                                       *NEW
```

Table B-3 - Partial Listing Subroutine MASACC (Continued)

```
      WRITE(6,500)(MASCON(IZZ),IZZ=1,NM)
  500 FORMAT(10H MASCON = 9D13.6)
      GO TO 3002
      ENTRY MASACC(PART,MASMAT)
      IF(NMCCON.EQ.0.AND.NMCSOL.EQ.0)RETURN
      IKNT=0
      NN2=NMCSOL+NMCCON
      DO 2003 II=1,3
      DO 2003 JJ=1,NN2
      PART(II,JJ)=0.0D0
 2003 CONTINUE
      TTEST=DABS(TBLOCK(4))
      T1=TBLOCK(1)-TTEST/2.0D0
      T2=TBLOCK(1)+TTEST/2.0D0
      DO 2001 JZY=1,NMCODE
      KODES=MASCW(JZY)
      KODNO=FLD(0,18,KODES)
      DO 2000 JKZ=1,3
      IF(FLD(2*JKZ+8,2,KODES).EQ.0) GO TO 2000
      IKNT=IKNT+1
      IDUM4=(KODNO-1)*9+6
      IDUM5=(KODNO-1)*9+7
      IF(MASCON(IDUM4).GT.T2) GO TO 2000
      IF(MASCON(IDUM5).LT.T1) GO TO 2000
      IF(MASCON(IDUM4).GT.T1) GO TO 1990
       TS=T1
      GO TO 1991
 1990  TS=MASCON(IDUM4)
 1991  CONTINUE
       IF(MASCON(IDUM5).GT.T2) GO TO 1992
      S=(MASCON(IDUM5)-TS)/TTEST
      GO TO 1993
 1992  S=(T2-TS)/TTEST
 1993  CONTINUE
      CNT=.553959390-2
 1999 IEZF=IKNT
      IDUM6=3*(JKZ-1)+1
      PART(1,IEZF)=S*(RBECI(IDUM6)/WEIGHT)*CNT
      PART(2,IEZF)=S*(RBECI(IDUM6+1)/WEIGHT)*CNT
      PART(3,IEZF)=S*(RBECI(IDUM6+2)/WEIGHT)*CNT
 2000 CONTINUE
 2001 CONTINUE
      RETURN
 3002 RETURN
      END
```

END OF COMPILATION: 27 DIAGNOSTICS. 28 MAY 76 19112109 0 02460176 1* 451 (DEL

MASACC SYMBOLIC 28 MAY 76 19112109 1 02011470 36 1 (DEL

MASACC CODE RELOCATABLE 0 02011534 14 136

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Table B-4 - Partial Listing Subroutine MCNPRC

```
      CALL T2INIT (RTA)
  304 NUMMM = NUMMM + 1
      BRAD = MASCON(5,JWASR)
      ARAD = MASCON(6,JWASR)
      THK  = MASCON(7,JWASR) / .201
      IPR = 0
      CALL ALPHA(IPR,THK,ARAD,AAA)
      CALL ALPHA(IPR,THK,BRAD,BAA)
      IPR = 1
      CALL ALPHA(IPR,THK,ARAD,AAPA)
      CALL ALPHA(IPR,THK,BRAD,BAPA)
      IPR = 0
      CALL GAMMA(IPR,THK,ARAD,AGA)
      CALL GAMMA(IPR,THK,BRAD,BGA)
      IPR = 1
      CALL GAMMA(IPR,THK,ARAD,AGPA)
      CALL GAMMA(IPR,THK,BRAD,BGPA)
      WRITE(KDNUM1) (ALPH(L),L=1,322)
  305 CONTINUE
      IF (NMCID .EQ. 0) GO TO 360
      DO 350 I=1,NMC
      I2   = MCID(I)
      IF (I2.EQ.0) GO TO 360
      IF ( I2 .GE. 1 .AND. I2 .LE. NMC ) GO TO 310
      IERR = IERR + 1
      CALL FLIP(1,IFLP)
      WRITE (KOUT,3000) I2
 3000 FORMAT(40H ERROR ILLEGAL VALUE ON MCID CARD VALUE=,I10)
      GO TO 350
  310 CONTINUE
      DO 340 K=1,4
      IF (NMSCON(14+K , I2) .EQ. 0) GO TO 320
      IPACK = 2
      GO TO 330
  320 MASCON(K,I2) = MASNOM(K,I2)
      NMCON = MAX(NMCON,I2)
      IPACK = 1
  330 NMSCON(14+K , I2) = IPACK
  340 CONTINUE
  350 CONTINUE
C
C                 CHECK IF S/C GREATER THAN NMCON
C
  360 NMCODE = 0
      NMCPLM = 0
      NMCSOL = 0
      NMCCON = 0
      INIT = 0
      LOC = 1
      I = 0
  365 CALL DECODE(I0,N,IPAR)
      IF (IPAR) 370,450,370
  370 IF (N(1).GT.NMCON) GO TO 395
      J =(N(1)-1)/4 + 1
      IBIT = MOD((N(1)-1)*8,32) + IABS(2*IABS(IPAR)-2)
      K = N(1)
      IPAR1=IABS(IPAR)                                                 NEW
      IF(NMSCON(14+IPAR1,K).EQ.0) GO TO 395                            NEW
```

```
      IF (INIT.EQ.N(1)) GO TO 375                                      ..-1
      INIT = N(1)
      LOC = LOC + 1
      I = 0
      NMCODE = NMCODE + 1
```

Table B-4 - Partial Listing Subroutine MCNPRC (Continued)

```
00517            IF (INIT.EQ.N(I)) GO TO 375                                          **-1
00521            INIT = N(I)
00522            LOC = LOC + 1
00523            I = 0
00524            NMCODE = NMCODE + 1
00525            CALL PACK(0,19,MSCOD(NMCODE),N(I))
00526            CALL PACK(29,7,MSCOD(NMCODE),LOC)
00527        375 I = I+1
00530            IF (IPAR) 380,400,385
00533        380 J = 2
00534            NMCCON = NMCCON + 1
00535            GO TO 390
00536        385 J = 1
00537            NMCSOL = NMCSOL + 1
00540        390 IBIT = 10 + 2 * IABS(IPAR) - 2
00541            CALL PACK(IBIT,2,MSCOD(NMCODE),J)
00542            IF (IPAR.NE.1) NMCPLH = NMCPLH + 1
00544            GO TO 365
00544  C
00544  C                 ERROR
00544  C
00545        395 IERR = IERR + 1
00546            CALL FLIP(1,IFLP)
00547            WRITE (KOUT,3910) N(I)
00552       3910 FORMAT (73H ERROR - CANNOT SOLVE OR CONSIDER THE PARAMETER SPECIFI
00552           .ED FOR MASCON NO. ,I4,12H - NOT INPUT)
00553            CALL DELCOD
00554            GO TO 365
00554  C
00554  C                 END OF MASCONS
00554  C                 TEST FOR CHECKMODE PRINT
00554  C
00555        400 IF (NMCON.EQ.0) GO TO 900
00557            IF (LISTIT.NE.YES) GO TO 500
00561            CALL FLIP(4,IFLP)
00562            WRITE (KOUT,4000)
00564       4000 FORMAT (25H CKMODE PRINT FROM MCNPRC/  9X,10HMASS RATIO,18X,
00564          1   8HLATITUDE,19X,9HLONGITUDE,19X,8HALTITUDE )
00565        410 DO 420 J=1,NMCON
00570            CALL FLIP(1,IFLP)
00571            WRITE(KOUT,4010)  (MASCON(I,J),I=1,7)
00577       4010 FORMAT(7D27.18)
00600        420 CONTINUE
00600  C
00600  C                 WRITE MASCONS ON DRUM
00600  C
00602        500 CALL RANLAS(KDRUM1,NDRUM(9))
00603            WRITE (KDRUM1) ((MASCON(I,J),I=1,NPARS),J=1,NMCON)
00614            WRITE(KDRUM1)(MSCOD(I),I=1,NMCODE)                                   .NEW
00622            WRITE(KDRUM1)((NMSCON(I,J),I=15,21),J=1,NMCON)                       .NEW
00633            WRITE(KOUT,4011) ((MASCON(I,J),I=1,7),J=1,NMCON)                      .NEW
00644       4011   FORMAT(7D18.10)                                                    .NEW
00645            CALL FLIP(NMCON/7+4,IFLP)                                            **-3
00646            WRITE (KOUT,2000)
00650            K =(NMCON- 1)/4 + 1
00651            WRITE (KOUT,4030) ((NMSCON(J,I),J=15,21),I=1,K)
00662            CALL FLIP(NMCODE/7 + 2,IFLP)
00663            WRITE (KOUT,4040) NMCODE,(MSCOD(I),I=1,NMCODE)

00672       4030 FORMAT(10H NMSCON = /( 7(2X,O12)))
```

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```
CD                NTTRG - NUMBER OF TIME TRIGGERS
CD                NYTRG - NUMBER OF DEPENDENT VARIABLE TRIGGERS
CD                TBLOCK- TIME BLOCK FOR TRAJ
CD            CARD
CD                NONE
CD            TAPE
CD                NONE
CD
CD        OUTPUT
CD            CALLING SEQUENCE
CD                NONE
CD            COMMON
CD                CDAR   - DRAG COEFFICIENT
CD                IBSVE  - BTAB POINTER INITIALIZED HERE FOR BODATT
CD                IWSVE  - WTAB POINTER INITIALIZED HERE FOR VMASS
CD                IFLAG  - CONTROL FLAG FOR INTEGRATOR
CD                JPNT   - ETAB POINTER INITIALIZED HERE FOR BODATT
CD                KFLAG  - CONTROL FLAG FOR INTEGRATOR
CD                TBLOCK- TIME BLOCK FOR TRAJ
CD            CARD
CD                NONE
CD            PRINT
CD                NONE
CD            TAPE
CD                NONE
CD
CD     REMARKS AND RESTRICTIONS
CD                NONE
CD
CD     SUBROUTINES REQUIRED
CD                TRJOUT(TRJWRT), DAUX, ENDSTP, TRIGER
CD
CD     METHOD
CD                TRAJ IS A DOUBLE PRECISION NUMERICAL INTEGRATOR FOR THE
CD                SOLUTION OF A SYSTEM OF SECOND-ORDER ORDINARY DIFFERENTIAL
CD                EQUATIONS.  IT IS BASED ON THE COWELL-ADAMS METHOD, EMPLOY-
CD                ING AN EIGHTH-ORDER BACKWARDS DIFFERENCE FORMULA SUMMED
CD                TWICE.  A RUNGA-KUTTA FOURTH-ORDER STARTER IS USED TO
CD                OBTAIN INITIAL DIFFERENCES.  TRAJ CONTAINS LOGIC FOR
CD                SELECTION OF INITIAL STEP SIZE AND SEQUENTIAL AUTOMATIC
CD                HALVING AND DOUBLING ACCORDING TO A BOUND ON LOCAL TRUNCATION
CD                ERROR.  CONTROL IS RETURNED TO THE USER WHEN TARGET VALUES
CD                OF INDEPENDENT AND DEPENDENT VARIABLES ARE HIT.  TRAJ
CD                ULTIMATELY PRODUCES A TRAJECTORY TAPE CONTAINING A MESH
CD                OF DIFFERENCE LINES WHICH MAY LATER BE PROCESSED BY THE
CD                ISAAC-NEWTON COMBINATION FOR INTERPOLATION/INTEGRATION
CD                AT SPECIFIC VALUES OF THE INDEPENDENT VARIABLE.
CD
CD. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
      SUBROUTINE TRAJ(TTRG,YTRG,Y,YP,YPP,DIF,SEVENT,VTAB)                *NEW
      DOUBLE PRECISION VTAB(5,1)                                          *NEW
      COMMON/VENX/VOTAB(5,50)                                             *NEW
      IMPLICIT DOUBLE PRECISION (A-H,O-Z),INTEGER(I-N)                    **-1
C...BEGIN STANDARD COMMON FOR SUBROUTINE TRAJ               10/04/72
      DOUBLE PRECISION  CBLOCK,TBLOCK
      DOUBLE PRECISION CDA02M(2),CDAR
      DOUBLE PRECISION CONST, CONFIX, SCRCOM, EBUF
      DIMENSION     CBLOCK(   5),NTTRG (   2),TBLOCK(   4)



      COMMON/      /CONST (250), KONST (250), CONFIX (400)
```

```
      COMMON/      /CONST (250), KONST (250), CONFIX (400)
C,                  KONFIX ( 500), LENGTH ( 100), IPOINT (   60)
C,                  KPOINT (   60), SCRCOM ( 200), EBUF (1000)
      DOUBLE PRECISION TRAJD
      DOUBLE PRECISION TLLTH(3)
      COMMON / TRAJEC / TRAJD ( 200), ITRAJ (   40)
      EQUIVALENCE (CBLOCK(1)    ,  CONST  (   64) )
     1 ,           (IFLAG        ,  ITRAJ  (    2) )
     1 ,           (CDAR         ,  TRAJD  (  156) )
     1 ,           (IVENT        ,  KONST  (  226) )
     1 ,           (CDAD2M(1)    ,  CONST  (   69) )
     1 ,           (JPNT         ,  ITRAJ  (   12) )
     1 ,           (IBSVE        ,  ITRAJ  (   11) )
     1 ,           (IWSVE        ,  ITRAJ  (   14) )
     1 ,           (KFLAG        ,  ITRAJ  (    1) )
     1 ,           (KVEH         ,  KONFIX (   10) )
     1 ,           (NTTRG (1)    ,  LENGTH (   47) )
     1 ,           (NY           ,  LENGTH (   27) )
     1 ,           (NYTRG        ,  LENGTH (   49) )
     1 ,           (TBLOCK(1)    ,  CONFIX (  170) )
      EQUIVALENCE(NYTAB,KONST(227))                                    .NEW
      EQUIVALENCE (TLLTH(1),TRAJD(153))
C...END STANDARD COMMON FOR SUBROUTINE TRAJ                 10/09/72
      DOUBLE PRECISION KTTRG
      DOUBLE PRECISION  Y(1),YP(1),YPP(1),DIF(13,1),TTRG(2,1),TRGT(2),
     1 YTRG(5,1),AA(9),SIG(10),GAM(9),SSIG(9),GGAM(9),SIGS(9),GAMS(9)
C INTEGRATION COEFFICIENTS
      DATA (SSIG(I),I=1,9)     /  9751299.D0, 10081456.D0, 10457524.D0,
     1                 10899720.D0, 11391620.D0, 11975040.D0, 12640320.D0,
     2                 13305600.D0, 13305600.D0/
      DATA (GGAM(I),I=1,9)     /  2082753.D0,  2140034.D0,  2207940.D0,
     1                  2293440.D0,  2394000.D0,  2530080.D0,  2721600.D0,
     2                  3024000.D0,  3628800.D0/
      DATA (SIGS(I),I=1,9)     /  -339157.D0,  -376068.D0,  -432476.D0,
     1                  -521635.D0,  -583440.D0,  -665280.D0,  -665280.D0,
     2                        0.D0, 13305600.D0/
      DATA (GAMS(I),I=1,9)/         -57281.D0,   -67906.D0,   -82500.D0,
     1                  -103560.D0,  -136080.D0,  -191520.D0,  -302400.D0,
     2                  -604800.D0, -3628800.D0/
      LOGICAL  WFLAG ,FFLAG
C
C INITIALIZATION PROCEDURE
C
      CALL TRJOUT(DIF)
C
C     INITIALIZE DRAG,VENT,AND ATTITUDE MODELS
C
      IF(IVENT.EQ.0) GO TO 400
      CALL SHVNT1
  400 CONTINUE
      DO 425 I=1,3
  425 TLLTH(I)=0.D0
      IF(CDAD2M(1) .LE.0) GO TO 600
      COAR=CDAD2M(KVEH)
  600 CONTINUE
      JPNT=0
      IBSVE=1
      IWSVE=1

      STBLK4 = TBLOCK(4)
```


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```
      STBLK4 = TBLOCK(4)
      KTEST  = 1
C
C     END OF INITIALIZATION FOR DRAG,VENT, AND ATTITUDE MODELS
C
      IF (KFLAG.EQ.4 .OR. NTTRG(KVEH).LE.1)  GO TO 1000
      IF (TTRG(1,2) .LT. 0.D0)  GO TO 1000
      KTTRG = TTRG(2,2) - TBLOCK(1)
      KTTRG = DABS( KTTRG / TBLOCK(1))
      IF(CBLOCK(3) .LT. KTTRG) GO TO 1000
      CALL TRIGER(1,2,Y,YP,YPP,DIF,TTRG,YTRG,SEVENT)
 1000 NFLAG = ( KFLAG .LE. 3 )
      NY = NY
      IF (KTEST .NE. 2) GO TO 700
      IF(CBLOCK(2).GT.CBLOCK(1)) GO TO 700
      TBLOCK(4) = DABS(STBLK4)
      KTEST=1
  700 CONTINUE
      KFLAG=3
      IFLAG = +1
      TBLOCK(4)=TBLOCK(4)/8.0D0
      CALL DAUX                                                      .NEW
      IF (NYTRG.LE.0) GO TO 1005
      CALL ENDSTP (Y,YP,YTRG)
      DO 1002 I = 1,NYTRG                                          ENDSTP
 1002 YTRG(4,I) = YTRG(3,I)
 1005 CONTINUE
      KFLAG=0
      SGN = TBLOCK(4) / DABS(TBLOCK(4))
      TOLD       = TBLOCK(1)
      KC = 1
      TRGT(1) = TBLOCK(1)
      NERR = 3
      IF (NY.LT.3) NERR = NY
C CHOOSE INITIAL STEP
      DO 1110 I=1,NY                                                 ..-1
      DIF(1,I) = YPP(I)
      DIF(2,I)=Y(I)
 1110 DIF(3,I)=YP(I)
      IF (CBLOCK(2) .LE. CBLOCK(7))  GO TO 1230
      NRK = NERR
      KS = 0
      IIFLAG = -1
      SAVH = TBLOCK(4)
      ASSIGN 1130 TO KRK
 1120 DPA = SAVH/2.0D0
      TBLOCK(4)=SAVH
      KCNT = 1
      GO TO 7000
 1130 DO 1160 I=1,NY
      IF (KCNT.EQ.2) GO TO 1140
      DIF(4,I) = Y(I)
      GO TO 1150
 1140 DIF(5,I) = Y(I)
 1150 Y(I) = DIF(2,I)
      YP(I) = DIF(3,I)
 1160 YPP(I) = DIF(1,I)
      TBLOCK(1) = TOLD
```

```
      IF (KCNT.EQ.2) GO TO 1170
      KCNT = 2
```

```
C  END RESTORATION AND RETURN
C  TIME TRIGGER ONLY LOGIC
 6038 TBLOCK(1) = TBAR
      NOS = NY
      ASSIGN 6550 TO KOS
      ASSIGN 6040 TO KEXT
      GO TO 8000
 6040 KFLAG = KSAVE
      TRGT(1) = TBLOCK(1)
      IF (KFLAG.LT.2) GO TO 6050
      KSTEP = 8
      W = TBLOCK(4)
      TBLOCK(4) = V
      NYSAV2=NY
      NY=NYSAV1
      ASSIGN 6045 TO KWT
      GO TO 9000                                        .NEW
 6045 IF(KFLAG.EQ.3) GO TO 6047                         .NEW
      GO TO 6046                                        .NEW
 6047 IF(NVTAB.EQ.0) GO TO 6061                         .NEW
      DO 6048 JJ=1,NVTAB                                .NEW
      DO 6048 II=1,5                                    .NEW
      VTAB(II,JJ)=VOTAB(II,JJ)                          .NEW
 6048 CONTINUE                                          .NEW
 6061 CONTINUE                                          .NEW
      RETURN                                            .NEW
 6046  TBLOCK(4)=W                                      ..-2
      NY=NYSAV2
      GO TO 1000
 6050 IF(KFLAG.EQ.0) GO TO 6057
      IF(NYTRG .LE. 0)GO TO 6056
      IPTR = 1
      ASSIGN 6055 TO KRESET
      GO TO 6500
 6055 IPTR = 2
      KFLAG=0
      ASSIGN 6057 TO KRESET
      GO TO 6500
 6056 KFLAG=0
.DIAGNOSTIC.  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
 6057 IF (TBLOCK(1).EQ.TRGT(2)) GO TO 6015
      GO TO 6005
C  END TIME ONLY LOGIC
C  BEGIN SCAN Y
 6060 SUBAR = -1.00
      DO 6065 I = 1, NYTRG
      IF (YTRG(1,I).LT.0.000) GO TO 6065
      D = YTRG(4,I) - YTRG(2,I)
.DIAGNOSTIC.  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF (D.EQ.0.000) GO TO 6065
      R = YTRG(5,I) - YTRG(2,I)
      IF (R*D.GT.0.000) GO TO 6065
      YTRG(1,I) = 1.00
      S = R / (R-D)
      SUBAR = DMAX1(S,SUBAR)
 6065 CONTINUE
C  END SCAN Y
      IF (SUBAR.LT.0.000) GO TO 6014

      ASSIGN 6066 TO KHIDE
      GO TO 6600
```


19

Table B-6 - Partial Listing Subroutine TRIGER

```
      ISPECY = 1 - M
      NCOLD = NCENTR(KVEH)
      IF ( NCENTR(KVEH)  .NE.  11)GO TO 310
      NCENTR(KVEH)  = 3
      YTRG(1,3) = 0.D0
      YTRG(2,2) = CSPHIN(3)
      YTRG(2,3) = CSPHIN(11)
      GO TO 350
  310 IF (NCENTR(KVEH) .NE. 3)GO TO 320
      IF( M .EQ. 2)GO TO 325
      NCENTR(KVEH) = 11
      YTRG(1,3) = -1.D0
      YTRG(2,2) = CSPHIN(11)
      GO TO 350
  320 IF( NCENTR(KVEH) .EQ. 10)GO TO 340
  325 NCENTR(KVEH) = 10
      DO 330 I=2,10
      J= I-1
      YTRG(1,I)= 0.D0
  330 YTRG(2,I) = CSPHIN(J)
      GO TO 350
  340 J = M-1
      NCENTR(KVEH) = J
      YTRG(2,2) = CSPHIN(J)
      DO 345  I=3,10
  345 YTRG(1,I) = -1.D0
      IF ( J .NE. 3) GO TO 350
      YTRG(1,3) = 0.D0
      YTRG(2,3) = CSPHIN(11)
  350 CONTINUE
      ICENTR = NCENTR(KVEH)
      CGMR(11) = GMLUNT
      IF ( ICENTR .EQ. 11 ) GO TO 3010
      IF ( ICENTR .NE. 3 ) GO TO 3090
      IF ( K16 .LT. K15 ) GO TO 3090
C  READ EARTH POTENTIAL INTO VSTR
      CALL RANSET ( KDRUM1 , NDRUM(7) )
      READ ( KDRUM1 ) ( IVSTR(I) , I = K15 , K16 )
      CALL GPOTA ( IVSTR(MCWEJ1) , IVSTR(MCWEJ1+3) , IVSTR(MCWEC1) ,
     1                 IVSTR(MJE1) , IVSTR(MCSE1) )
      GO TO 3070
 3010 IF ( K18 .LT. K17 ) GO TO 3020
C  READ MOON POTENTIAL INTO VSTR
      CALL RANSET ( KDRUM1 , NDRUM(8) )
      READ ( KDRUM1 ) ( IVSTR(I) , I = K17 , K18 )
      CALL GPOTA ( IVSTR(MCWMJ1) , IVSTR(MCWMJ1+3) , IVSTR(MCWMC1) ,
     1                 IVSTR(MJM1) , IVSTR(MCSM1) )
 3020 CONTINUE                                                          .NEW
 3080 CONTINUE                                                          .NEW
      CGMR(11)=GMLUNT                                                   .NEW
 3090 CONTINUE                                                          ..-8
  372 YTRG(2,1) = .95D0 * CRCB(ICENTR)
.DIAGNOSTIC.  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF (TMINT .EQ. TBLOCK(1) .AND. IREQ(NCOLD) .EQ. 3 .AND. ICENTR
     1.EQ. ITABOD) GO TO 375
      ITABOD = ICENTR
      IREQ(NCOLD) = 3
      TMINT = TBLOCK(1)

      CALL EPHEM1
      CGMR(11) = GMLUNT
```

Table B-6 - Partial Listing Subroutine TRIGER (Continued)

```
      CALL EPHEM1
      CGMR(I1) = GMLUNT
      IF(NCENTR(KVEH).EQ.I1) CGMR(I1)=GMLUNT                              .NEW
  375 IF(LISTIT.NE.YES)GO TO 378                                          ..-1
    7 FORMAT(16H0CENTRAL BODY = I5)
      EPMIN = TBLOCK(1) - TMIN(KVEH)
      WRITE(6,1) NAME(L),M,EPMIN,TBLOCK(4),(Y(I),YP(I),YPP(I),I=1,3)
  378 CONTINUE
      DO 380 I=1,3
      Y(I) = Y(I) + TABOUT(I,NCOLD)
  380 YP(I) = YP(I) + TABOUT(I+3,NCOLD)
      NTOT = NSOLEP + NCNSEP
      XMU1 = CMU + CGMR(I0)
      IF (NTOT .NE. 0)  CALL EPHACC(NTOT,ICENTR,NCOLD,Y,YP,XMU1)
      IF(LISTIT.NE.YES)GO TO 385
      CALL FLIP(7,IFLP)
      WRITE (KOUT,7) ICENTR
      EPMIN = TBLOCK(1) - TMIN(KVEH)
      CALL FLIP(10,IFLP)
      WRITE (KOUT,1) NAME(L),M,EPMIN,TBLOCK(4),(Y(I),YP(I),YPP(I),I=1,3)
  385 KFLAG = 2
      IF (TBLOCK(4) .GE. 0.D0)  GO TO 390
      KFLAG = 4
      GO TO 391
  390 II = NVEHSE(KVEH)
      IF (II .LE. NEVTMX(KVEH))  GO TO 393
  391 NVEHSE(KVEH) = NVEHSE(KVEH) - 1
      GO TO 395
  393 II = (NVEHSE(KVEH)*2) - 1
      SEVENT(II) = M + ISPECY
      IF( LISTIT .NE. YES ) GO TO 394
      CALL FLIP(3,IFLP)
      WRITE(KOUT,1964) II, SEVENT(II), ISPECY, M, TBLOCK(1)
 1964 FORMAT(1H0,43X,21H*** SPECIAL EVENT *** / 1X,I10,D15.6,2I10,5X,
     1        D26.18)
  394 ISPECY = 0
      SEVENT(II+1) = TBLOCK(1)
      IF (M .EQ. 18)  YTRG(1,18) = -1.D0
  395 RETURN
  400 IF ( LNDTR (KVEH) .EQ. 0 ) GO TO 401
      NVEHSE(KVEH) = NVEHSE(KVEH) - 1
      GO TO 395
  401 ISPECY = 2
      JK = 2
      IF (TBLOCK(4) .LT. 0.D0) JK = 1
      IF(RTYPE .EQ. HRTYPE(2) .OR. RTYPE .EQ.HRTYPE(5) ) GO TO 409
      IF (IFITFL .GT. 1)  GO TO 410
      DCLIM(JK,KVEH) = TBLOCK(1)
      GO TO 415
  409 DCLIM(JK,KVEH) = TBLOCK(1)
  410 DTLIM(JK,KVEH) = TBLOCK(1)
  415 IITCNT = IITCNT + 1
      IF (LISTIT .NE. YES) GO TO 416
      CALL FLIP(3,IFLP)
      WRITE (KOUT,13) DCLIM, DTLIM
   13 FORMAT (9H0DCLIM = ,4D23.15/9H DTLIM = ,4D23.15)
      EPMIN = TBLOCK(1) - TMIN(KVEH)
      CALL FLIP(10,IFLP)

      WRITE(KOUT,1) NAME(L),M,EPMIN,TBLOCK(4),(Y(I),YP(I),YPP(I),I=1,3)
```

Table B-7 - Partial Listing Subroutine TRAJRD

```
      I3 = 21
      I4 = 17
      I5 = 16
      I6 = 23
      I7 = 22
  159 CONTINUE
C
C  Y TRIGGERS
C
      IF ( K2 .LE. K1 ) GO TO 200
      CALL RANSET ( KDRUM2 , NDRUM(I1) )
      READ ( KDRUM2 ) ( VSTR(I) , I = K1 , K2 )
C
C  ALIGNMENT CONSTRAINT TABLE
C
  200 IF ( K4 .LE. K3 ) GO TO 300
      CALL RANSET ( KDRUM2 , NDRUM(I2) )
      READ ( KDRUM2 ) ( VSTR(I) , I = K3 , K4 )
C
C  ALIGNMENT TABLE
C
  300 IF ( K6 .LE. K5 ) GO TO 400
      CALL RANSET ( KDRUM2 , NDRUM(I3) )
      READ ( KDRUM2 ) ( VSTR(I) , I = K5 , K6 )
C
C  LOP BURN CONSTRAINT TABLE
C
  400 IF ( K8 .LE. K7 ) GO TO 500
      CALL RANSET ( KDRUM2 , NDRUM(I4) )
      READ ( KDRUM2 ) ( VSTR(I) , I = K7 , K8 )
C
C  IGS BURN CONSTRAINT TABLE
C
  500 IF ( K10 .LT. K9 ) GO TO 600
      CALL RANSET ( KDRUM2 , NDRUM(I5) )
      READ ( KDRUM2 ) ( VSTR(I) , I = K9 , K10 )
C
C  LOP BURN TABLE
C
  600 IF ( K12 .LE. K11 ) GO TO 700
      CALL RANSET ( KDRUM2 , NDRUM(I6) )
      READ ( KDRUM2 ) ( VSTR(I) , I = K11 , K12 )
C
C  IGS BURN TABLE
C
  700 IF ( K14 .LE. K13 ) GO TO 800
      CALL RANSET ( KDRUM2 , NDRUM(I7) )
      READ ( KDRUM2 ) ( VSTR(I) , I = K13 , K14 )
C
C  POTENTIAL
C
  800     CONTINUE
C
C  EARTH POTENTIAL
C
      IF ( K16 .LT. K15 ) GO TO 1100
      CALL RANSET ( KDRUM1 , NDRUM(7) )
      READ ( KDRUM1 ) ( VSTR(I) , I = K15 , K16 )

C     ...N POTENTIAL
```

```
C
C  MOON POTENTIAL
C
  900 IF ( K18 .LT. K17 ) GO TO 1000
      CALL RANSET ( KDRUM1 , NDRUM(8) )
      READ ( KDRUM1 ) ( VSTR(I) , I = K17 , K18 )
C
C  MASS CONS
C
 1000 IF ( K20 .LT. K19 ) GO TO 1100
      CALL RANSET(KDRUM1,NDRUM(9))
      READ ( KDRUM1 ) ( VSTR(I) , I = K19 , K20 )
      IF ( K22 .LT. K21 )  GO TO 1050
      READ ( KDRUM1 ) ( VSTR(I) , I = K21,K22 )
 1050 IF(K36.LT.K35) GO TO 1100
      CALL RANSET(KDRUM1,NDRUM(90))
      DO 1060 II=K35,K36,644
      II161 = II + 642
 1060 READ(KDRUM1)  (VSTR(I), I = II , II161)
C
C              VTAB/BTAB/ETAB/WTAB TABLES
C
 1100 CONTINUE
C
C              VTAB
C
      IF(K24.LT.K23) GO TO 1200
      CALL RANSET(KDRUM2,NDRUM(75))
      READ(KDRUM2)(VSTR(I),I=K23,K24)
C
C              BTAB
C
 1200 IF(K26.LT.K25) GO TO 1300
      CALL RANSET(KDRUM2,NDRUM(76))
      DO 1250 J=K25,K26,24
      L=J+23
      READ(KDRUM2) (VSTR(I),I=J,L )
 1250 CONTINUE
      CALL RANGET(KDRUM2,ISAVE)
C
C              ETAB
C
 1300 IF(K28.LT.K27) GO TO 1400
      CALL RANSET(KDRUM2,ISAVE)
      READ(KDRUM2) (VSTR(I),I=K27,K28)
C
C              WTAB
C
 1400 IF(K30.LT.K29) GO TO 1500
      CALL RANSET(KDRUM2,NDRUM(77))
      READ(KDRUM2) (VSTR(I),I=K29,K30)
C
C              LANDMARK TABLE
C
 1500 IF(K32.LT.K31) GO TO 1550
      CALL RANSET (KDRUM2,NDRUM(25))
      READ(KDRUM2) (VSTR(I),I=K31,K32)
C

C  TRAJ LINK INITIALIZATION
C
```

Table B-8 - Partial Listing Subroutine TRJSUP

```
     1 ,              (RTYPE      ,   KONFIX ( 313) )
C***END STANDARD COMMON FOR SUBROUTINE TRJSUP          10/09/72
      INTEGER  VSTR(1)
      DIMENSION ITJ(3,2)
      DATA ITJ /6HVEH 1 ,6HTRAJEC,6HTORY   ,
     *           6HVEH 2 ,6HTRAJEC,6HTORY   /
C
C
      CALL RTIME(-2,ITJ(1,KVEH))
      GMLUNT = CGMR(11)
      J = 6 * (KVEH - 1) + 1
      NY = 3 * ( NDPR + 1 + KONSOL(1,J) + KONSOL(2,J) )
      NSZ = NSZ1
      IF ( KVEH .EQ. 2) NSZ = NSZ2
      CALL DAUXA(VSTR(MY1),VSTR(MYP1),VSTR(MSUNP),NSZ,VSTR(MYPP1),
     *            VSTR(MVTAB),VSTR(MRTAB),VSTR(METAB),VSTR(MWTAB) )
      CALL TRIGA( VSTR )
      IF ( ICR .EQ. 11 ) GO TO 10
      IF ( ICR .NE. 3  ) GO TO 20
      CALL GPOTA( VSTR(MCWEJ1) , VSTR(MCWEJ1+3) , VSTR(MCWEC1) ,
     1            VSTR(MJE1) , VSTR(MCSE1) )
       GO TO 15                                                       *NEW
   10 CALL GPOTA( VSTR(MCWMJ1) , VSTR(MCWMJ1+3) , VSTR(MCWMC1) ,      **-1
     1            VSTR(MJM1) , VSTR(MCSM1) )
   15 IF(NMCON.EQ.0.OR.KVEH.EQ.2) GO TO 20                            *NEW
      CALL MCINIT(VSTR(MMCON1),VSTR(MMCCW1),VSTR(MMCAGA),VSTR(MMCAGA),  *NEW
     1 VSTR(MVTAB))                                                   *NEW
   20 CONTINUE                                                        **-3
      IF ( NBRN(KVEH) .EQ. 0 ) GO TO 200
      CALL PHASEA ( VSTR(MTTRG1) , VSTR(MAUX1) , VSTR(MCNLP1) ,
     1              VSTR(MCNIG1) , VSTR(MIGB1) , VSTR(MLPB1) ,
     2              VSTR(MALGN1) , VSTR(MINY1) , VSTR(MLNY1) ,
     3              VSTR(MCNAL1) , VSTR(MY1)   , VSTR(MYP1)  )
  200 CALL TRAJ   ( VSTR(MTTRG1) , VSTR(MVTRG) , VSTR(MY1)   ,
     *              VSTR(MYP1)   , VSTR(MYPP1) , VSTR(MDIF1) ,
     2  VSTR(MSEV1),VSTR(MVTAB))                                      *NEW
C                                                                     **-1
C   WRITE SPECIAL EVENTS ON DRUM
C
      IF ( NVEHSE(KVEH) .EQ. 0 ) GO TO 300
      IF ( IFITFL .LT. 2 .AND. RTYPE .EQ. HRTYPE(3) ) GO TO 300
      N1 = MSEV1
      N2 = MSEV1 + ( NVEHSE(KVEH) * 4 ) - 1
      CALL RANLAS ( KDRUM2 , NDRUM(KVEH+56) )
      WRITE ( KDRUM2 ) ( VSTR(I) , I = N1 , N2 )
  300 CONTINUE
      CGMR(11) = GMLUNT
      CALL RTIME(2,ITJ(1,KVEH))
      RETURN
      END

END OF COMPILATION:          NO  DIAGNOSTICS.
TRJSUP          SYMBOLIC         09 MAR 78  19:15:43   0  02410224  13   218  (DELETE
TRJSUP   CODE   RELOCATABLE      09 MAR 78  19:15:43   1  02315210  36     1  (DELETE
                                                       0  02315254  14    37

GL MAP,* HOPE,HOPE                                                 01 DEC 78    4
```

Table B-9 - Partial Listing Subroutine HOPE

```
@L MAP,* HOPE.HOPE                                                  01 DEC 78
-40,44
                     SEG        MAIN
                     CHN        1
                     SEG        MAIN1-REINIT
                     CHN        2
                     SEG        MAIN2-AA
          AA          SEG       INPUT-SEPAR-DATIN-QQC04-DECODE-SKIP-TIMEX-REFCOR;
                                -QQSLAF-*(QQSDA1,QQSDA2,QQSDA3,INPCHK,CVPRT,GBPRT,RUNPRT;
                                ,ICNPRT,CONPRT,A,B,C,D,E,F,H,BB,CC,DD,SDSPRT;
                                ,APRPRC,VPRPRC,WPRPRC)
          A          SEG        QQINPT-QCONST-*(DUMPRC,POTPRC,COVPRC,EDTPRC,TIMPRC,A3,B3,;
                                C3,D3,G,ATTPRC,VNTPRC)
          B           SEG       INIT-INTER-CONTIM-SCALPS-SC3DOP
          BB          SEG       DPPLM-ACIXYZ
          C           SEG       TRJPRC-SETCOD-SETTRG-ASSIGN
          CC          SEG       SETTAB-*(ATAMAT,EE)
          EE          SEG       GETBND-GETSCL-GETLBL-GETVAL-GETCAT
          D          SEG        SRTMRG-*(OBSSRT,MERGE)
          DD          SEG       BAPRT-APPRT-SDPRT
          E           SEG       TMSPRT
          F           SEG       ONPRT-*(SBPRT,LNDPRT,STRPRT,ODDPRT)
          H          SEG        CRDPRC-FNDSYM-*(CRDPRI,CRDMRG,CRDIMG)
          A3         SEG        SFNPRC-GBOBS-BNDPRC
          B3          SEG       STRPRC-SIGPRC-OBOBS
          C3         SEG        BIAPRC-LNDPRC
          D3          SEG       MCNPRC-ONPRC
          G           SEG       BAPRC-*(BATIM,CKALGN,BAFILL,BAWRT,CKBURN)
                      BLK       DATIN
                      BLK       QQC04
                     CHN    4
                     SEG  MAIN4-SUPER-*(;
                                FAIRD,FAISUP,POSTRD;
                                ,PSTSUP,COVRD,COVSUP,DCRD,GG)
          GG         SEG        SUBSUP-DCSTOR-DCSUP-*(ORCOMP,ONBORD)
                      BLK       DCSTOR
                     CHN    3
                    SEG        MAIN3-SUPTRJ-*(TRAJRD,QQ)
QQ1 SEG DRAG-BODY-MATPLY-OUTER-BODATT-VMASS-SHVENT-MASACC-SHVNT1-;
            *(JACHIA,CDESA,USSR)
QQ2 SEG SOLRAD-IGSCON-LOPCON
QQ3  SEG        IGSBRN-LOPBRN-SJMULT-;
       SCAN
          QQ    SEG        TRJSUP-TRAJ-TRJOUT-PHASE-TRIGER-ENDSTP-DAUX-GPOT-PIMOD;
                           -READTP-TLKUP;
                           -*(QQ1,QQ2,QQ3)
          QQ1 SEG DRAG-BODY-MATPLY-OUTER-BODATT-VMASS-SHVENT-MASACC-SHVNT1-;       *NEW
```

ORIGINAL PAGE IS OF POOR QUALITY

```
                   *(JACHIA,COESA,USSR)                                  *NEW
      002 SEG SOLRAD-IGSCON-LOPCON                                       *NEW
      003  SEG        IGSBHN-LOPBRN-SJMULT-1                             *NEW
                SCAN                                                     *NEW

              CHN 5                                                      **-5
              SEG   MAINS-SUPPRO-*(PROPRD,LL)
      LL      SEG   PRPSUP-TRJPRO-STTAPE-UVW-*(VECPRT,RELATE,MM)
      MM      SEG   COVA-NRTRAJ-*(PPLPC,CROTAT,MABAT,PRINIT)
              BLK    STTAPE

              CHN        8
              SEG        MAINP-SUPDD-*(DDOD,AA7)
      AA7      SEG       DDSUP-BB7-CATAPE-*(GRSPRT,EAINIT,MPVSTR,DD7,EE7,CC7)
      CC7      SEG       FAMIPX-NRTH-KEPLER-INTRP1-COOT
      DD7     SEG   OUHCAL-DELAY-RISE-*(RANGE,DOPLER,RANRAT,ANGLE,SPART,REFRAC,1
                         FPHACC)
      EE7     SEG        ODSIM-FF7-GETT-*(PRTALN,LNPART,EXPADD,ALLOW,OCCULT,1
                         NOISE,VHFMNG,SEX HT,RADAR,LNRADR,TAPRED)
      FF7     SEG   PRTIAL-*(CWRTT,DPRT,COMPT)
      BB7     SEG        DCSTOR-CAVEC-IMPULT-RN2S
              BLK        DCSTOR

              CHN        9
              SEG   MAINY-SUPCRD-*(CRDRD,TT)
      TT      SEG CRDSUP-CRDGEN-CRDSAV

MAP LCP 1104 0036
   HOPE            SYMBOLIC                      02 SEP 78  04:09:33   0  02404407     12     63  IDELETE
   HOPE    CODE    PROCESSED MAP                 02 SEP 78  04:09:31   1  02377152     64      1  IDELETE
                                                                       2  02377246     69      1
                                                                       3  02377342   1536      1
                                                                       4  02402342    312      1
                                                                       5  02403032    444      1
                                                                       6  02403726    324      1
                                                                       7  02404432    888      1
                                                                       8  02406222    132      1
                                                                      62  02406476     12      1


DENQ XQT HOPE                                                        01 DEC 78

        LINK        1
        LINK        2
        LINK        4
        LINK        3
        LINK        5
        LINK        8
        LINK        9
DRUM LENGTH 070510
```

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OF POOR QUALITY